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TECHNICAL MEMORANDUM

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TITLE: BODEPE - IBM 360 Computer Code for the SNAP-8 Boiler Heat and Momentum Transfer Analysis

ABSTRACT

The method of the thermal design analysis using a computer program coded in FORTRAN IV and the structure of the computer code is described for a counter-flow "once through" type NaK-to-Hg boiler. The heat and momentum transfer correlations in this code are those established from the wetting and non-wetting two-phase flow models in helical flow passage.

Key Words: NaK, Mercury, Vapor Quality, Heat Transfer, Pressure, Temperature, Two-Phase Flow, Wetting, Helix

APPROVED:

DEPARTMENT HEAD J. R. Pope

Note: The information in this document is subject to revision as analysis progresses and additional data are acquired.

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I. INTRODUCTION

The BODEPE computer program is intended for the SNAP-8 boiler heat and momentum transfer analysis. The analytical correlations are based on wetting and non-wetting two-phase flow models postulated in the different vapor quality regions of the boiler. Conventional single-phase heat transfer correlations were utilized for the analysis of the preheat section. The heat transfer in the superheat section was considered in the light of a helical flow regime. The latter involves the determination of forced and free convection heat transfer effects on the working fluid. The make-up of the code permits it to calculate the minimum plug insert and total boiler length requirements at any boiler design specification. The code also permits the evaluation of the boiler performance characteristics at many off-design operating conditions. The results of the calculations are provided in tabular form showing the nodal boundary state conditions of the working fluids and the local heat and momentum transfer parameters.

II. METHOD OF ANALYSIS

The basic method of the analysis is to subdivide the boiler length into a series of small nodal increments and to write the coupling heat and momentum transfer correlations for each length element. The boiler preheat and superheat sections are subdivided by taking equal increments of the mercury temperature rise. Similarly, the vapor quality region is subdivided by taking equal increments of the vapor quality. The solution of the coupling equations in each node provides the local thermal and dynamic operating parameters, node length and node boundary state conditions. The latter serve as input values for the following node calculations.

III. DESCRIPTION OF THE PROGRAM

BODEPE is written in modular form with a main program acting as a calling program for a series of subroutines which perform various segments of the calculations. The flow chart of the program is shown in Figure 1. The flow charts of the various subroutines of this program are shown in figure 2 through 9. There are eight subroutines tied directly into the

main program. The subroutine identifications and their functions are as follows:

READ(JOJO) - Provides the input data. It reads one (1) comment card and ten (10) data cards and checks for their proper sequence in each data card set. In case of improper card order, the data compilation is discontinued and the error identified by appropriate print-out statement prior to return to the main program. The success or failure of input data read-in operation is transmitted to the main program by JOJO=1 or 2, respectively. The input card listing is provided in Table 1. The flow chart is shown in Figure 2.

POWBAL - Calculates the thermal power requirements and the NaK flow rate or exit temperature. As shown in Figure 3, the flow pass in this subroutine depends on input values provided for the NaK exit temperature (TNBO) and the total NaK flow rate (WNTOTT). There are two possibilities: (a) TNBO $\neq$ 0, WNTOTT = 0, and (b) TNBO = 0, WNTOTT $\neq$ 0. Case (a) determine the total NaK flow rate, WNTOT, using TNBO as argument. Case (b) determines the boiler NaK exit temperature, TNBO, using WNTOT as argument. The zero input values of TNBO and WNTOTT are forcing the calculations through the prescribed flow passes.

CONSTS - As shown in Figure 4, this subroutine calculates the thermal pass resistances and the thermal and geometric constants for three different mercury flow passage containment configurations and three different mercury flow passage internal geometries. The flow passages considered in this code are: single metal tubes, bimetal tubes and double containment tubes with stagnant liquid-metal layer separating the outer and the inner tube. The internal geometries are identified by IGEOM

number. IGEOM = 1 refers to multipassage plug insert (MPP) and single fluted helix (SFHX) geometries placed in the mercury tube. Two (2) different single fluted helixes, SFHXI and SFHX, are employed when IGEOM = 2. The program also can utilize a single mercury tube internal geometry, e.g., SFHX, throughout the boiler length, in such a case IGEOM = 3. The swirl wire turbulator geometry is identified with SFHX when the center bar diameter is reduced to zero (DBAR = 0) and the helical strip thickness (THICK) reduced to a negligible value.

MPPPH(NOGO) - Refers to boiler preheat section analysis (Figure 5). The input data are provided from the preceeding subroutines via a series of common statements. The calculation is initiated with the trial values for the boiler inlet pressure and the preheat section pressure drop. The determination of the latter involves the iteration procedure in this subroutine. The determination of the former involves the iteration procedure extending through a portion of the main program. When the radial and axial temperature distribution of composite wall heat transfer pass is not of interest, this portion of the calculation can be omitted by setting the input value of JTABLE = 0. The failure of the iteration process to meet the convergence criterion is recorded by an appropriate error message and the program is returned to BODEPE with NOGO = 1. This flag notation terminates the calculation and causes the main program to use the next input data set. In case of satisfactory convergence test, this subroutine identifies the geometry of the case and assigns appropriate flag value (NOGO = 2 or 3) to be utilized in the main program.

MPPXP(IOIO) - Is utilized to calculate the local boiling heat and momentum transfer parameters in the plug insert vapor quality region (XP) next to liquid-vapor interface. Both the multipassage plug insert (MPP) geometry or the single-fluted helix (SFHXI) geometry can be used in this subroutine. Depending on an arbitrary input value provided (DELMPP), this subroutine calculates the plug insert vapor exit quality (X(IMAX)) when DELMPP $\neq$ 0. These conditions refer to boiler design and performance analysis respectively. The calculations of this subroutine are completed with one of the possible three IOIO flag values. Flag value IOIO = 1 indicates that the calculated pressure (PXP) level is acceptable and the main program will call in action the next subroutine (SFHXX). Flag value of IOIO = 2 requires the correction of the trial value of the boiler inlet pressure. Consequently, the main program transmits the calculation back to subroutine MPPPH. IOIO = 3 says that allowable iteration passes have been reached and the calculation of the current case is terminated by the main program.

This subroutine also uses a root finding subroutine to find the roots of nonlinear equations. The subroutine, called ROOT, uses function programs RPROOT or XPROOT to calculate the non-dimensional liquid film thickness at the tube wall.

SFHXX - Contains the heat and momentum transfer correlations applicable to the geometry of a single-fluted helix or swirl wire turbulator in the vapor quality region up to x = 100%. The local wetting and non-wetting heat and momentum transfer parameters and node boundary state conditions are calculated on the basis of nodal vapor quality incrementation. The program also utilizes the subroutine ROOT in conjunction with the function programs ROROOT AND TFROOT. The former defines the non-dimensional liquid film thickness at the tube wall. The latter defines the temperature drop across the mercury film in droplet-rivulet two-flow regime. Once the 100% vapor quality point is reached, the calculation is terminated and the program returned to BODEPE.

SFHXSH(NONO) - Calculates the superheat section length, establishes the local heat and momentum transfer parameters and nodal boundary state conditions of the working fluids. In case of the boiler design calculations, the input value of DELTOT = 0.0 and the total boiler length (ALSH(IX)) is calculated. In case of the boiler performance evaluation, the input value of DELTOT represents the available total boiler length. The calculated boiler exit pressure (PEXIT) is tested against the prescribed input value of PHBO. Nonconvergence is identified by NONO = 1 and the calling program initiates another iterative pass. In case of convergence the program completes the closing calculations and provides the flag notation NONO = 2 for the main program. This subroutine also utilizes the subroutine ROOT in conjunction with the function program SHROOT, which defines the temperature drop between the tube wall and the bulk mercury vapor.

OUTPUT - This subroutine has the capacity to print out the results in several forms. Only the input data table and a single-page summary printout of the results is provided when ITABLE is set to zero. The setting of ITABLE = 1 and JTABLE = 1 results in complete printout of the results. When JTABLE = 0, the calculation and print-out tables of the composite wall temperature profiles is omitted. The flow diagram of this segment of the program is shown in Figure 9.

Complete listing of the program is provided in Appendix A.

IV. NaK and Hg PROPERTIES

The NaK and mercury transport properties are entered into calculating subroutines by calling the required fluid property subroutine. Each such a subroutine contains tabular data covering the property of interest. The dependent variable of interest is interpolated from the tables using subroutine INT4 and the independent variable.

V. INPUT DATA

The input data card format is given in Table 1. The first card in each input data set must be the title card marked "001." The title card is followed by ten (10) input data cards marked "101 - 110" in ascending order. The last card is marked "0" in format I3. It terminates the program when no more input data are provided.

VI. PROGRAM LIMITATIONS

The use of this program is limited to "once through" type NaK-to-Hg boilers of counterflow configuration. The program can be used for other fluid combinations providing their transport properties are made available in the form of function subroutines. Only helical flow passage geometries can be utilized for the boiling fluid. The program accepts both a single helix or two different helixes placed in series in the boiling fluid tube. The series placement of the helixes limits the first helix (plug insert) vapor exit quality calculation up to the point of wetted boiling termination. Because the drywall boiling heat and momentum transfer correlations are not provided in subroutine MPPXP, the calculation in this subroutine is limited by (X(IX) ≤ XWET.

VII. PRINCIPAL DESIGN CORRELATIONS

The determination of the preheat section length and its heat transfer parameters is based on Dwyer's[1] correlation:

$$Nu = 7 + .025 \left[Pe - \frac{1.82Re}{(\epsilon_M/\nu)^{1.4}} \right]^{0.8} \qquad \text{(VII-1)}$$

The heat and momentum transfer correlations in the vapor quality region are those derived from the wetting and non-wetting, two-phase flow models.[2,3] The early vapor quality region containment in the MPP or SFHXI is treated as wetted boiling region with laminar annular liquid-film at the tube wall and turbulent vapor core. When expressed in non-dimensional form, the liquid film thickness is

$$\rho = \frac{r_1}{r_o} \qquad \text{(VII-2)}$$

In case of MPP, the non-dimensional film thickness ρ is the root of the following non-linear equation:

$$\frac{128}{\xi_{int}\beta} \frac{Y}{X} \frac{\left[(\rho^2 - \rho'^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta\rho_1)^2 \right]^3}{\left[\beta\rho + 2(\rho - \rho') + \pi\beta\rho' \right]} = (1 - \rho^2)^2 \qquad \text{(VII-3)}$$

where

$$X = \frac{\bar{x}\rho_o\mu_1}{(1-\bar{x})\rho_1\mu_o} \qquad \text{(VII-4)}$$

$$Y = \frac{N_1 N_2 r_o \mu_1}{\bar{x}\, W_{TOT}} \qquad \text{(VII-5)}$$

Knowing the liquid-vapor interface radius (r_1), the two-phase pressure drop factor is determined from:

$$\Phi = \frac{\left(\frac{\partial p}{\partial X}\right)_{TP}}{\left(\frac{\partial p}{\partial X}\right)_{GP}}$$

$$\Phi = \frac{\xi_{int}}{\xi_{tube}} \left[\frac{\beta r_1 + 2(r_1 - r_2) + \frac{1}{2}\pi\rho r_2}{\beta r_o + 2(r_o - r_2) + \frac{1}{2}\pi\rho r_2}\right]\left[\frac{(r_o - r_2^{\,2})\frac{\rho}{2} + \frac{\pi}{8}(\rho r_2)^2}{(r_1^{\,2} - r_2^{\,2})\frac{\rho}{2} + \frac{\pi}{8}(\rho r_2)^2}\right]^3 \qquad \text{(VII-6)}$$

The corresponding correlations for the geometry of SFHX are:

$$\left[\frac{1}{2} X \left(\frac{\mu_o}{\mu_1}\right)\left(\frac{1 - \rho^2}{\rho^3}\right) + \left(\frac{4\pi}{\xi_{int}}\right) XY \left(\frac{\mu_o}{\mu_1}\right)^2\right] +$$

$$\sqrt{\left(\frac{4\pi}{\xi_{int}}\right) X^2 Y \left(\frac{\mu_o}{\mu_1}\right)^3 \left(\frac{1 - \rho^2}{\rho^3}\right) + \left(\frac{4\pi}{\xi_{int}}\right)^2 X^2 Y^2 \left(\frac{\mu_o}{\mu_1}\right)^4} = \frac{1}{\rho} \qquad \text{(VII-3A)}$$

$$\Phi = \frac{\xi_{int}}{\xi_{tube}} \left(\frac{r_o}{r_1}\right)^5 \left[1 - \left(\frac{2r_1^{\,2}}{r_o^{\,2} - r_1^{\,2}}\right)\left(\frac{\rho_1}{\rho_o}\right)\left(\frac{1 - \bar{x}}{\bar{x}}\right)\right]^2 \qquad \text{(VII-6A)}$$

The derivation of Equations (VII - 2) to (VII - 6) is provided in Appendix C.

The heat transfer in wetted boiling region is calculated from

$$Nu = C \frac{D_1}{\alpha} \qquad \text{(VII-7)}$$

where C and α is a boiling mode constand and liquid film thickness respectively.

For drywall boiling or droplet-rivulet flow regime, the Nusselt modulus is

$$Nu = \frac{6.6\ n\ (\frac{1}{8n}\ \bar{y}_L)^{8/15}}{(3600\ k_v\ \Delta T_F\ g/h_{fv}\ \rho_v^{1/2}\ \rho_f^{1/2}\ u_{TV}^3)^{2/5}} \qquad \text{(VII-8)}$$

where

$$u_{TV} = \frac{G_v}{\rho_v}\ \frac{\pi D}{P} \qquad \text{(VII-9)}$$

$$\bar{y}_L = \frac{1 - \bar{x}}{1 + (\rho_f/\rho_v - 1)\ \bar{x}} \qquad \text{(VII-10)}$$

$$n = n_o \frac{x_o}{x} \qquad \text{(VII-11)}$$

The solution for the temperature drop across the boiling fluid film is obtained from

$$\Delta T_F + R\ C_1\ \Delta T_F^{3/5} - \Delta T_B = 0 \qquad \text{(VII-12)}$$

where

$$C_1 = \frac{12 k_v}{De_h}\ \frac{6.6\ n\ (\frac{1}{8n}\ \bar{y}_L)}{\left[g\ k_v/3600\ h_{fv}\ (\rho_v \rho_F)^{1/2}\ u_{TV}\right]^{2/5}} \qquad \text{(VII-13)}$$

$$R = \frac{R_1}{R_4}\ \frac{1}{h_N} + \frac{R_1}{R_{M34}}\ \frac{R_4 - R_3}{k_{SS}} + \frac{R_1}{R_{M23}}\ \frac{R_3 - R_2}{k_{ST}} + \frac{R_1}{R_{M12}}\ \frac{R_2 - R_1}{k_{Ta}} \qquad \text{(VII-14)}$$

The two-phase flow pressure drop factor in drywall boiling regime is determined from Marlinelli-Nelson correlation $\Phi_{gtt} - f(\sqrt{X_{tt}})$ plotted in Figure 10 where

$$X_{tt} = \left(\frac{\rho_v}{\rho_f}\right)^{.5} \left(\frac{\mu_f}{\mu_v}\right)^{.1} \left(\frac{1 - \bar{x}}{\bar{x}}\right) \qquad \text{(VII-15}$$

The general form of two-phase flow pressure drop correlation is:

$$\Delta P_{TP} = \Phi \; \xi_v \frac{\Delta L}{D_e} \frac{(\bar{x}G)^2}{2g_c \rho_v} \qquad \text{(VII-15)}$$

The heat transfer in vapor superheat section is determined from the following correlations:

$$h_{SH} = h_{forced} + h_{free} \qquad \text{(VII-16)}$$

where

$$h_{free} = \frac{12k_v}{De_t} Nu_\ell(7.1) \cdot \frac{\beta^{1/3}}{Re_l^{.13} \; Pr^{.07}} \left(\frac{\pi D_l}{p}\right)^{2/3} \left(\frac{De_t}{De_\ell}\right)^{2/3} \Delta T_F^{\;1/3} \qquad \text{(VII-17)}$$

The determination of ΔT_F requires the solution of the following correlation

$$\Delta T_F^{\;1.333} + \frac{R \cdot h_{forced} + 1}{R \cdot F} \Delta T_F - \frac{\Delta T_B}{R \cdot F} = 0 \qquad \text{(VII-18)}$$

where

$$F = \frac{12k_v}{De_t} Nu_\ell(7.1) \frac{\beta^{1/3}}{Re_\ell^{.13} \; Pr^{.07}} \left(\frac{\pi D_l}{p}\right)^{2/3} \left(\frac{De_t}{De_\ell}\right)^{2/3} \qquad \text{(VII-19)}$$

$$h_{forced} = \frac{12k_v}{De_h} Nu_{forced} \qquad \text{(VII-20)}$$

The helical frictional pressure drop coefficient for "vapor flow only" is determined from

$$\xi = \left[\left(\frac{.316}{Re_H^{.25}}\right)\left(\frac{A_H}{A_a}\right)^{1.75}\left(\frac{D_H}{D_a}\right)^{1.25} + .0584\left(\frac{\pi D_T}{p}\right)^3\left(\frac{D_T - t}{D_T + D_B}\right)\left(\frac{A_H}{A_a}\right)^2\left(\frac{D_H}{D_a}\right)\right]\cos\alpha_M \qquad \text{(VII-21)}$$

The derivation of the Eq. VII-21 is provided in Appendix C, Section C-6.

C-7 SINGLE-FLUTED HELICAL FLOW PASSAGES (SFHX) GEOMETRY[5]

SFHX is defined by:

D_T - tube ID

D_B - center bar diameter

t - helical strip thickness

p - pitch of SFHX

The geometric parameters are:

$R_T = \frac{D_T}{2}$ - tube radius

$R_B = \frac{D_B}{2}$ - bar radius

$\omega' = \frac{2\pi}{p}$ - constant

$p_{orth\ T} = 2\pi R_T^2 \omega'$ - orthogonal pitch, tube ID

$p_{orth\ B} = 2\pi R_B^2 \omega'$ - orthogonal pitch, bar diameter

$\mathcal{Z}_T = \frac{2\pi R_T}{\sqrt{1 + (R_T \omega')^2}} - t$ - wetted perimeter portion on tube ID

$\mathcal{Z}_B = \frac{2\pi R_B}{\sqrt{1 + (R_B \omega')^2}} - t$ - wetted perimeter portion on bar dia.

$\theta_B = \frac{2\pi}{1 + (R_B \omega')^2}$ - $\mathcal{Z}_B$ circular projection angle, radians

$$\theta_T = \frac{2\pi}{1 + (R_T\ \omega')^2}$$ - $\measuredangle_T$ circular projection angle, radians

$$Y = \left[R_T^{\ 2} + R_B^{\ 2} - 2R_TR_B \cos\left(\frac{\theta_B - \theta_T}{2}\right)\right]^{1/2}$$

- wetted perimeter portion on helical strip

$$P_W = \measuredangle_T + \measuredangle_B + 2Y$$ - total wetted perimeter of helical flow crossection

$$A_H = \left[\frac{p^2}{2\pi}\sqrt{1 + (\omega'\ R_T)^2} - \sqrt{1 + \omega'\ R_B)^2}\right] - t(R_T - R_B)$$

- helical flow crossection area

$$De_H = \frac{4A_H}{P_W}$$ - equivalent diameter, helical

$$A_\ell = \frac{\pi}{4}\ (D_T^{\ 2} - D_B^{\ 2})$$ - linear crossection

$$De_\ell = D_T - D_B$$ - linear equivalent diameter

$$\text{RATIOA} = \frac{A_H}{A_\ell}$$

$$\text{RATIOD} = \frac{De_H}{De_\ell}$$

VIII. SAMPLE PROBLEM

To demonstrate the use of the BODEPE computer program for a boiler design evaluation a sample problem is specified on 80 column input sheet as shown in Table 2. The nomenclature of the input sheet values is provided in Table 1. The problem involves the determination of the boiler operating local heat and momentum transfer parameters and the establishment of the boiler tube length at prescribed secondary fluid (Hg) flow rate, inlet and exit temperature and exit pressure. The primary fluid is NaK and its inlet temperature is defined. The design specification also defines the geometry of the Hg flow passage and the thermal pass and its materials. The BODEPE results of this problem are provided in Appendix B. They are:

OUTPUT 1 - is the summary tabulation of the results of the boiler design and performance analysis,

OUTPUT 2 - preheat section, nodal tabulation of local heat and momentum transfer parameters,

OUTPUT 3 - vapor low quality region in plug insert section, nodal tabulation of local heat and momentum transfer parameters,

OUTPUT 4 - vapor quality section, nodal tabulation of heat and momentum transfer parameters up to $x = 100\%$,

OUTPUT 5 - vapor superheat section, nodal tabulation of heat and momentum transfer parameters,

OUTPUT 6 - print-out of input data.

NOMENCLATURE

C	-	Constant
D_1	-	Tube ID
De	-	Equivalent diameter
De_h	-	Equivalent diameter, helical
De_l	-	Equivalent diameter, linear
De_t	-	Equivalent diameter, tangential
g_c	-	Gravitational constant
h_{fv}	-	Vaporization heat
h_{forced}	-	Heat transfer coefficient, forced convection
h_{free}	-	Heat transfer coefficient, free convection
h_{SH}	-	Heat transfer coefficient, vapor superheat region
N_1	-	Number of tubes
N_2	-	Number of flow passages in plug insert
Nu	-	Nusselt modulus
Nu_{forced}	-	Nusselt modulus, forced convection
Nu_l	-	Nusselt modulus, linear
n_o	-	Initial droplet population
n	-	Local droplet population
p	-	Pitch, pressure
Pr	-	Prandtl modulus
R	-	Thermal resistance between bulk NaK and mercury tube ID
Re_l	-	Reynolds modulus, linear flow
r	-	Radius
r_o	-	Radius, tube ID
r_1	-	Liquid-vapor interface radius in divided two phase flow model
r_2	-	Radius (See Appendix C, Figure C-3-2)
u_{TV}	-	Velocity, tangential

W_{TOT}	-	Flow rate, total
$\bar{x}$	-	Vapor quality, mean
x_o	-	Initial vapor quality
$\bar{y}_L$	-	Moisture content
ΔL	-	Lengths incriment
ΔP_{TP}	-	Pressure drop, two phase
ΔT_F	-	Temperature drop, mercury film
$\frac{\partial p}{\partial X}_{TP}$	-	Pressure gradient, two phase
$\frac{\partial p}{\partial X}_{GP}$	-	Pressure gradient, gas phase only
β	-	Angle, volumetric expansion
ξ_{int}	-	Liquid-vapor interface frictional pressure drop coefficient, divided two phase flow
ξ_{tube}	-	Frictional pressure drop coefficient, tube wall
$\mu_{f_1} \mu_o$	-	Dynamic viscosity, liquid
$\mu_{v_1} \mu_1$	-	Dynamic viscosity, vapor
$\rho = r_1/r_o$	-	
$\rho' = r_2/r_o$	-	See Appendix C, Figure C-3-2
ρ_f, ρ_o	-	Density, liquid
ρ_v, ρ_1	-	Density, vapor
Φ	-	Two phase pressure drop factor

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5. G. Mouritzen, "Forced Rotation of Flow in Pipes," GLM-36, Geoscience, Ltd., July 1965

FLOW CHART – BOiler DEsign and PErformance analysis

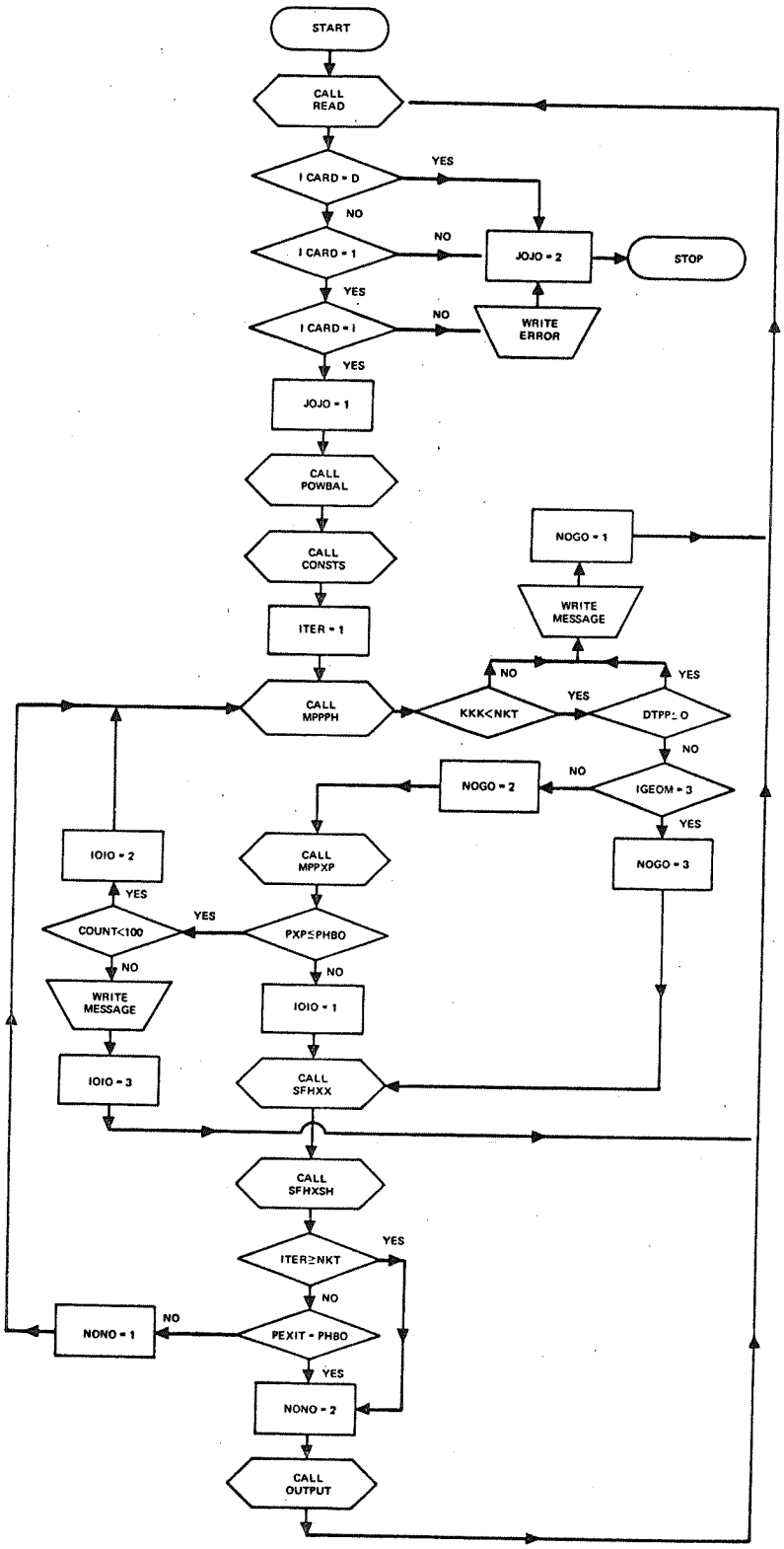
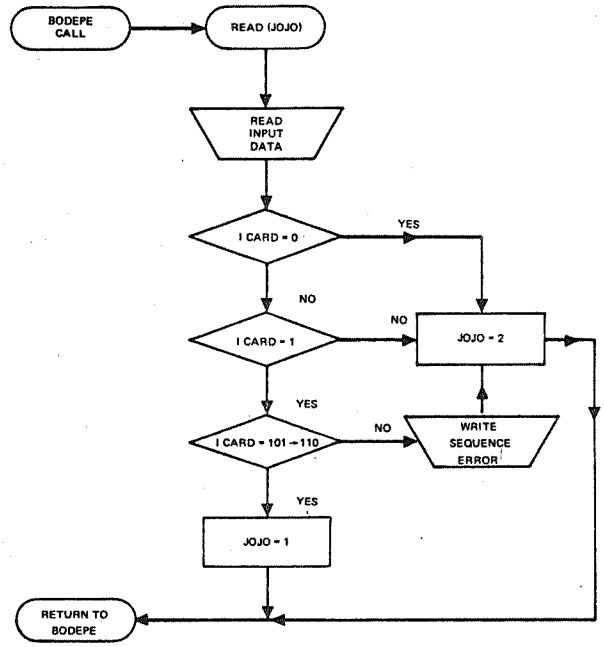


Figure 1

FLOW CHART – SUBROUTINE READ (JOJO)



NOMENCLATURE:

I CARD = 0	Last card in input data deck
I CARD = 1	First card of input data set, comment
I CARD = 101 → 110	Ten data cards of input data set

Figure 2

FLOW CHART – SUBROUTINE POWBAL

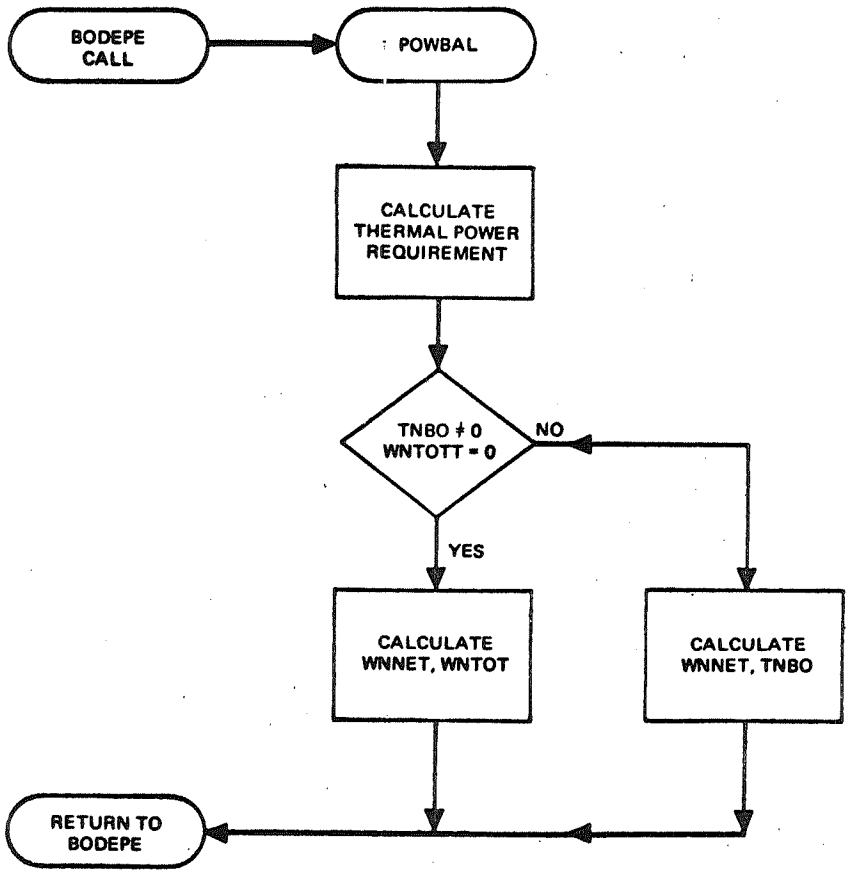


Figure 3

FLOW CHART – SUBROUTINE CONSTS

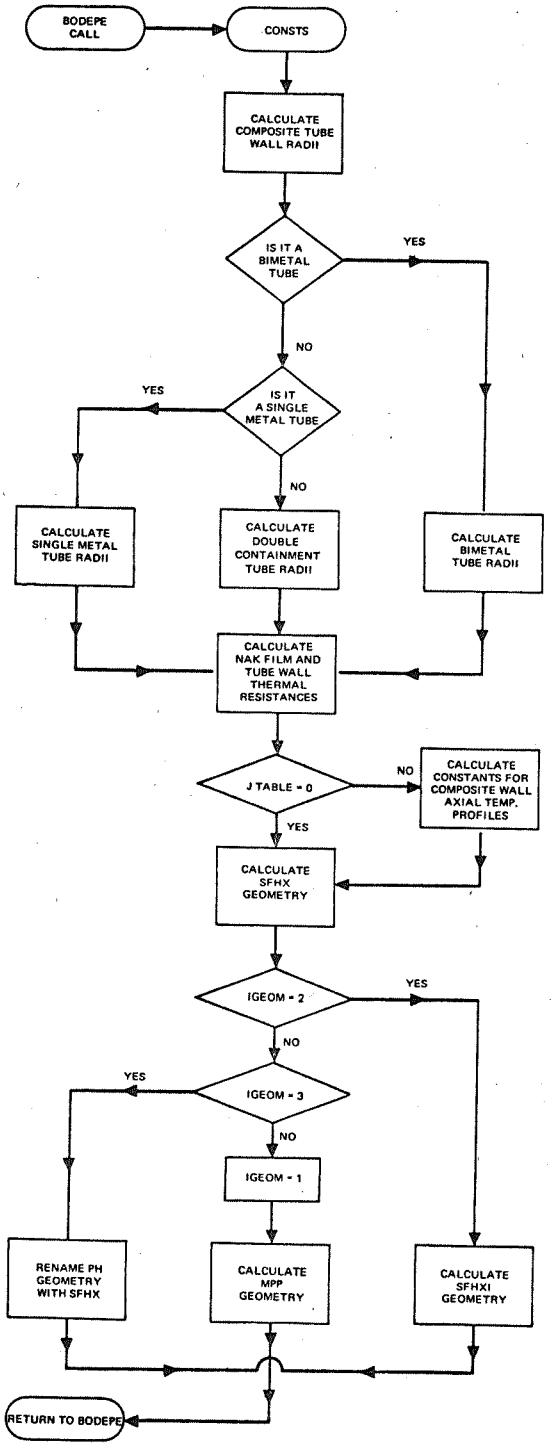


Figure 4

FLOW CHART -- SUBROUTINE MPPPH (NOGO)

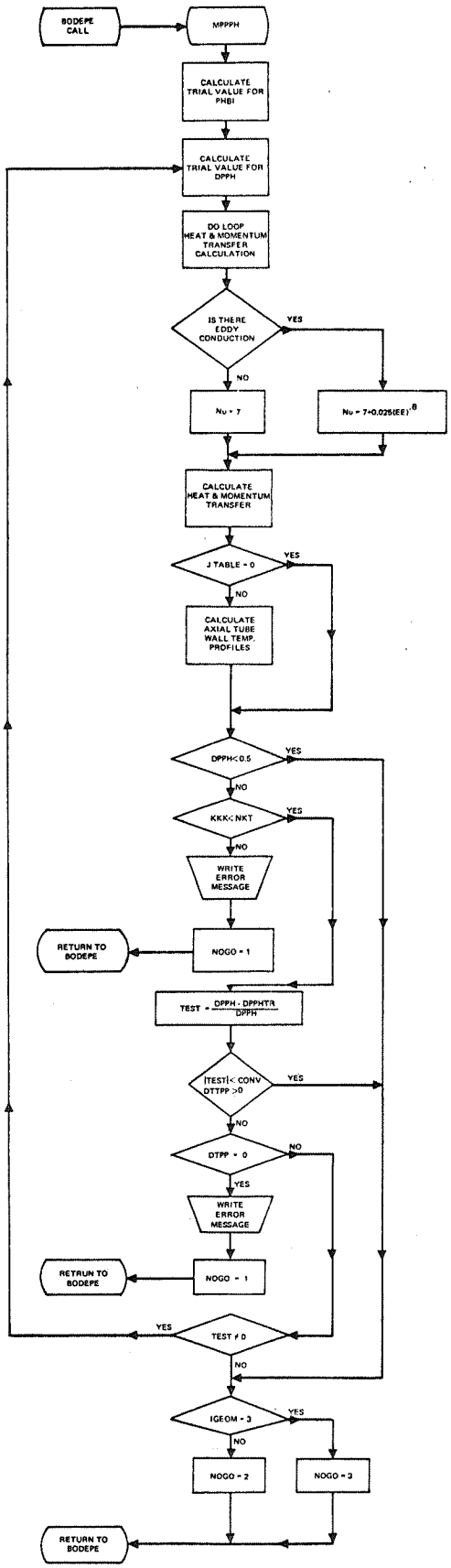
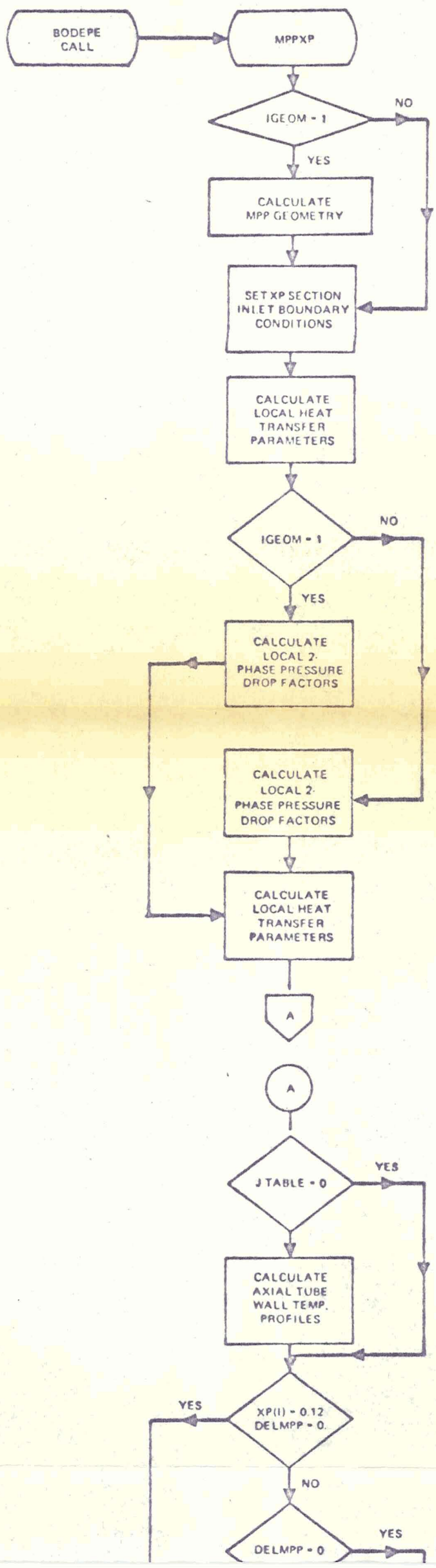


Figure 5

FLOW CHART – SUBROUTINE MPPXP (IDIO)



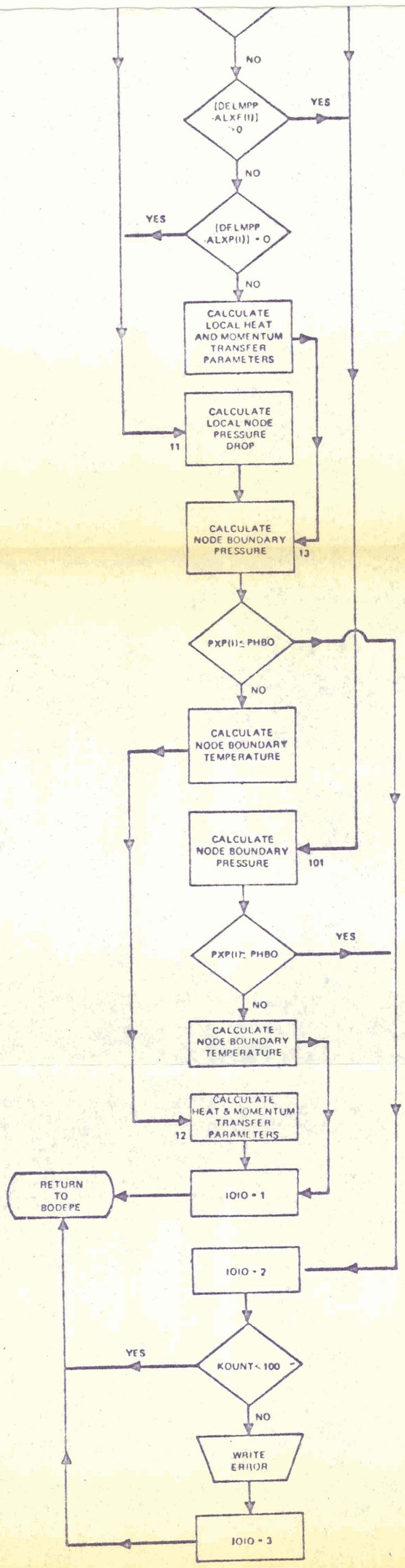

NO
[DELMPP -ALXF(I)] >0
YES
NO
YES
[DELMPP -ALXP(I)] = 0
NO
CALCULATE LOCAL HEAT AND MOMENTUM TRANSFER PARAMETERS
CALCULATE LOCAL NODE PRESSURE DROP
11
CALCULATE NODE BOUNDARY PRESSURE
13
PXP(I) ≤ PHBO
NO
CALCULATE NODE BOUNDARY TEMPERATURE
CALCULATE NODE BOUNDARY PRESSURE
101
PXP(I) ≥ PHBO
YES
NO
CALCULATE NODE BOUNDARY TEMPERATURE
CALCULATE HEAT & MOMENTUM TRANSFER PARAMETERS
12
RETURN TO BODEPE
IOIO = 1
IOIO = 2
YES
KOUNT < 100
NO
WRITE ERROR
IOIO = 3

Figure 6

FLOW CHART – SUBROUTINE SFHXX

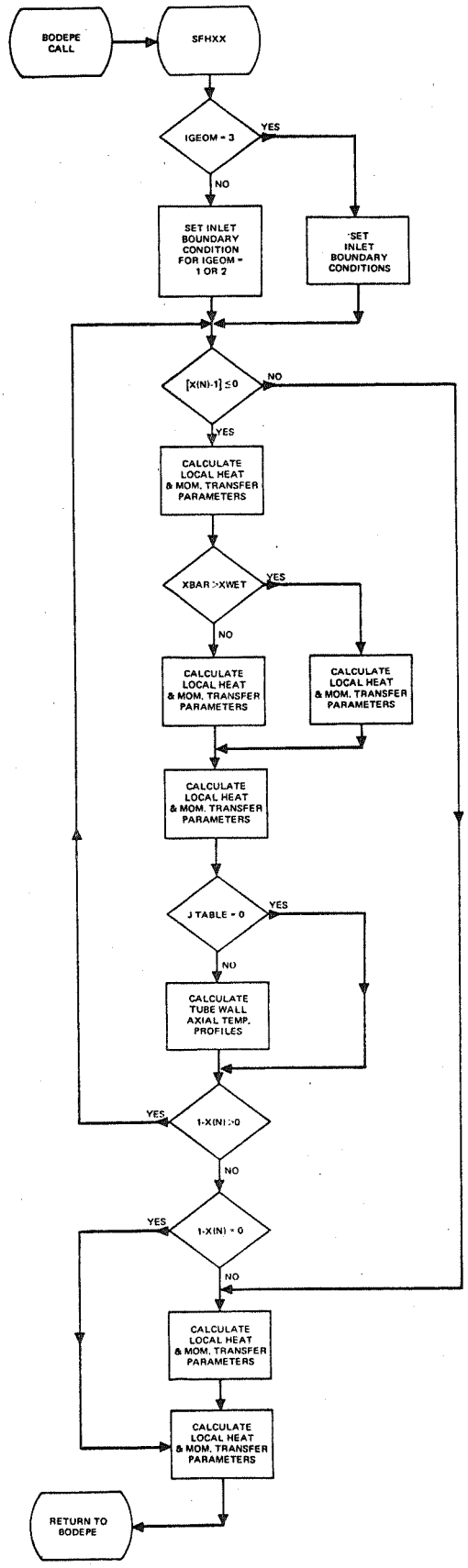


Figure 7

FLOW CHART – SUBROUTINE SFHXSH

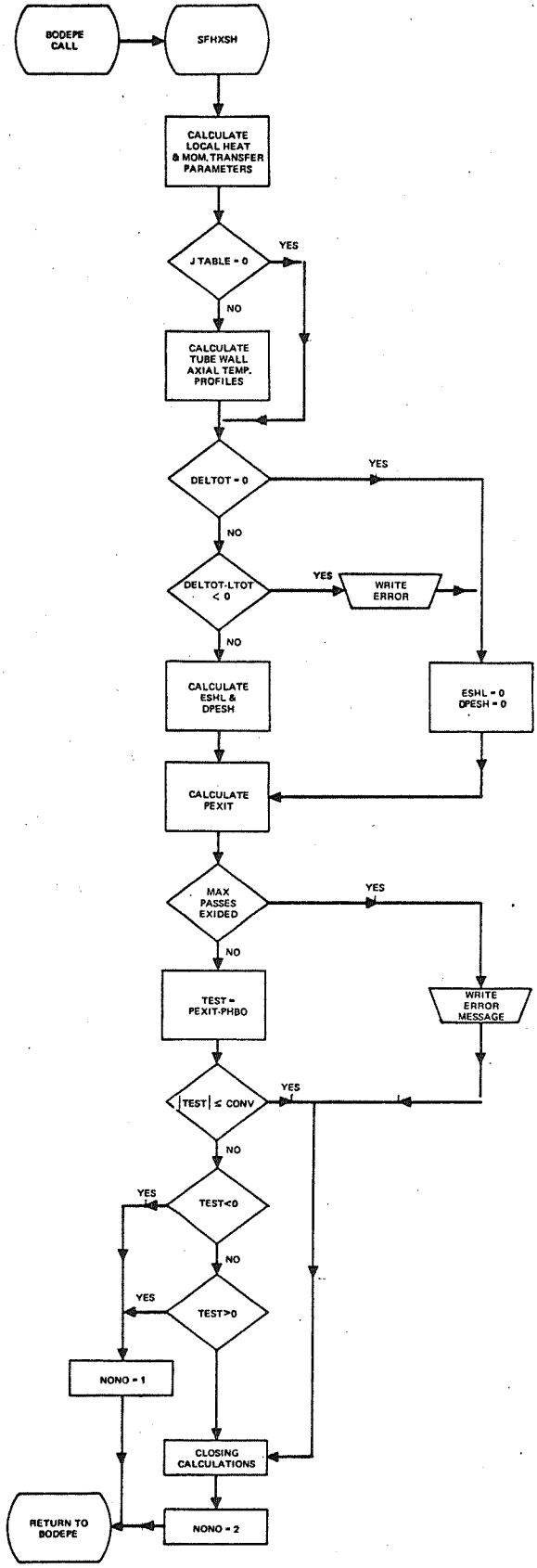


Figure 8

FLOW CHART – SUBROUTINE OUTPUT

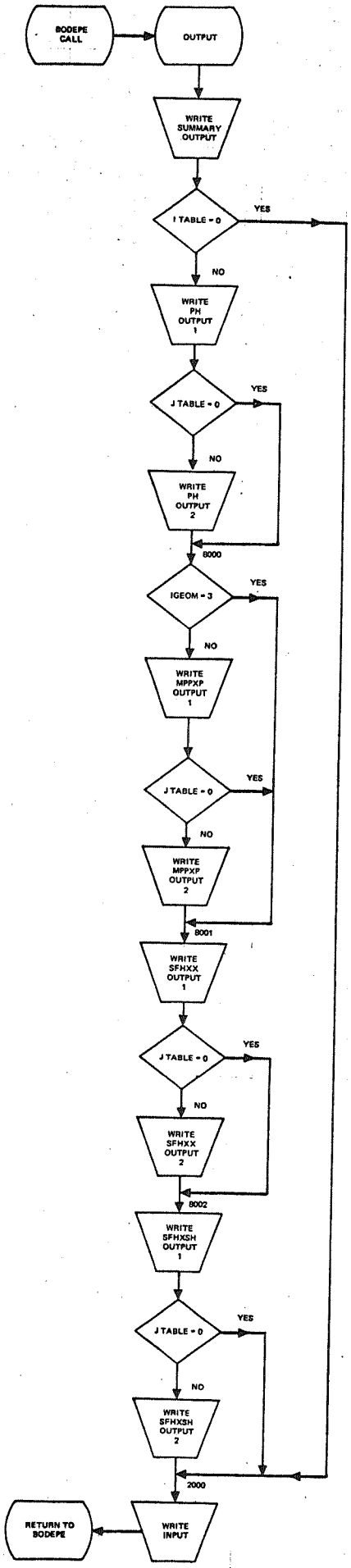
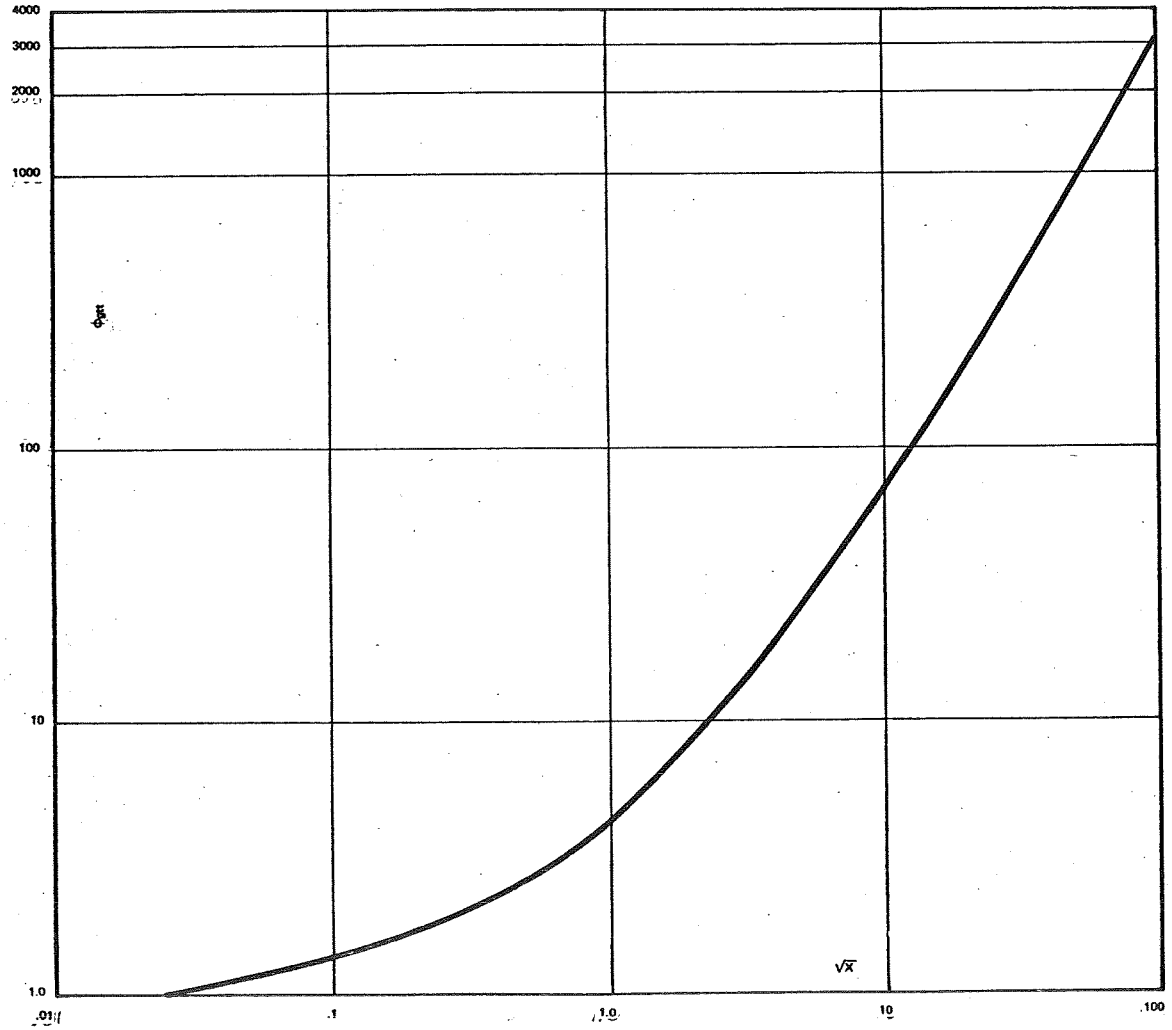


Figure 9



Plot of ϕ_{gtt} vs $\sqrt{X_{tt}}$

Martinelli-Nelson Pressure Drop Correlation for
Forced Convection Boiling Water
(ASME Trans. V.70, 1948)

Figure 10

TABLE I

INPUT DATA NOMENCLATURE FOR BODEPE CODE

Title Card:	FORMA I, 19A4, A1	
Col. 1 - 3:	001	
Col. 4 - 80:	Date and analysis identification comment	
Date Cards:	FORMAT I3, 9X, 5F12.0,	
Card "101":	WH	- Mercury flow rate, lb/hr,
	PHBO	- Mercury exit pressure, psia,
	THBI	- Mercury inlet temperature, °F,
	THBO	- Mercury exit temperature, °F,
	TNBI	- NaK inlet temperature, °F,
Card "102":	TNBO	- NaK exit temperature, °F
	QHL	- External heat loss, KW,
	D1	- Mercury tube ID, in.,
	TTA	- Tantalum tube wall thickness, in.,
	TNAK	- Stagnant NaK thickness, in.,
Card "103":	TSS	- Stainless steel tube wall thickness, in.,
	HNF	- NaK side film coefficient, B/hr - ft^2 - °F,
	AKNT	- Stagnant NaK containment tube (SS), thermal conductivity, B/hr - ft - °F,
	AKHT	- Mercury tube (Ta) thermal conductivity, B/hr - ft - °F,
Card "104":	DPHITR	- Preheat section pressure drop, high trial, psi,
	DPLOTR	- Preheat section pressure drop, low trial, psi
	CONV	- Convergence value, psi,
	CNT	- Iteration count
	PTRHI	- Mercury inlet pressure, trial, high, psia,
Card "105":	PTRLO	- Mercury inlet pressure, trial, low, psia,
	PMPP	- Pitch, multipassage plug, insert, in.,
	DMPP	- Multipassage plug insert channel width, in.,
	HMPP	- Multipassage plug insert channel height, in.,
	AN1	- Number of mercury tubes,

Card "106":	AN2	- Number of flow passages in multipassage plug insert,
	XL	- Number of nodal boundaries in preheat section,
	DX	- Vapor quality increment,
	DELMPP	- Multipassage plug insert length, ft.,
	FXINT	- Liquid-vapor interface frictional pressure drop coefficient for divided two-phase flow in plug insert section,
Card "107":	CONXP	- Constant defining the heat transfer mode for wetting two-phase flow model in plug insert section,
	DBAR	- Center bar dia of SFHX, in.,
	PHELIX	- Pitch of SFHX,
	THICK	- Strip thickness of SFHX,
	XWET	- Vapor quality at wetted boiling termination point,
Card "108":	FINTX	- Liquid-vapor interface frictional pressure drop coefficient for divided two-phase flow in SFHX,
	CONX	- Constant defining the heat transfer mode for wetting two-phase flow model in SFHX,
	DROPNO	- Initial droplet population per unit dia. length,
	XO	- Initial vapor quality in droplet-rivulet two-phase flow regime,
	XI	- Number of nodal boundaries in superheat section,
Card "109":	FORMAT I3, 9X, F12.0, 3I12, F12.0	
	DELTOT	- Total boiler length, ft.,
	ITABLE	- Table printout control,
	JTABLE	- Table printout control,
	IGEOM	- Mercury tube internal geometry identification,
	PITCH1	- Pitch of single passage mercury inlet end helix, in.
Card "110":	FORMAT I3, 9X, 5F12.0	
	DBAR1	- Center bar diameter of mercury inlet end helix, in.,
	THICK1	- Helical strip thickness of mercury inlet end helix, in.,
	C1	- Constant in MPP or SFHX1 pressure drop correlation,

C2	- Constant in helical flow passage, SFHX, pressure drop correlation,
WNTOTT	- Total NaK flow rate, lbm/hr

10-132-138

COMPUTING SCIENCES DIVISION
80 COLUMN INPUT SAMPLE

DATE _____ PROGRAM NO. BODEPE PROGRAMMED BY _____

1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
00108-26-68	SNAP-8 TA-55 DØUBLE CØNTAINMENT BØILER, MPP, SFNX, BØDE, LØ						
1.01	11800.	260.		500.	1260.	1280.	
1.02	1110.	12.		670	040	080	
1.03	035	3000.		13.	15.	40.	
1.04	1.		01	01	25.	400.	
1.05	250.	6.		080	032	7.	
1.06	16.	41.		02	0.0	50	
1.07	1.		1875	3.	030	88	
1.08	050	3.		10.	10	41.	
1.09	0.0		1	1	1	0.0	
1.10	0.0	0.0		1.	1.	0.0	

80 COLUMN INPUT SAMPLE

TABLE 2

STK. NO. D-1-C83

APPENDIX A

LISTING OF BODEPE CODE

```
C       BOILER DESIGN AND PERFORMANCE ANALYSIS(BODEPE)
C
        COMMON/ITER/ITER
        CALL READRE
      1 CALL READ(JOJO)
        GO TO(3,4),JOJO
      3 CALL POWBAL
        CALL CONSTS
        ITER=1
     51 CALL MPPPH(NOGO)
        GO TO(1,2,6),NOGO
      2 CALL MPPXP(IOIO)
        GO TO(6,51,1),IOIO
      6 CALL SFHXX
        GO TO 1
        CALL SFHXSH(NONO)
        GO TO(51,5),NONO
      5 CALL OUTPUT
        GO TO 1
      4 STOP
        END
        SUBROUTINE READ(JOJO)
C
C       READ IN DATA
        DIMENSION ERROR(20)
        COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
      1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
      2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
      3 PMPP,DMPP,HMPP,AN1,AN2,LX,
      4 DX,DELMPP,FXINT,CONXP,
      5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,XO,IX,DELTOT,
      6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
        COMMON/INPUT/ PHBOO,THBOO,TNBOO,PTRLOO,PTRHII,WNTOTT,XL,XI,CNT
        READ(5,5000) ICARD,DATE,COMENT
 5000   FORMAT(I3,19A4,A1)
        IF(ICARD.EQ.0) GO TO 88
        IF(ICARD.EQ.1) GO TO 100
   88   JOJO=2
        RETURN
   99   READ(99,5001) ERROR
 5001   FORMAT(20A4)
        WRITE(6,5050) ERROR
 5050   FORMAT(1H0,10X,34HTHE FOLLOWING CARD IS OUT OF ORDER/1H0,20X,
      1 20A4)
        JOJO=2
        RETURN
```

```
  100 READ(5,5002) ICARD
 5002 FORMAT(I3,9X,5F12.0)
 5003 FORMAT(I3,9X,F12.0,3I12,F12.0)
      IF(ICARD.NE.101) GO TO 99
      READ(99,5002) ICARD,WH,PHBO,THBI,THBO,TNBI
      READ(5,5002) ICARD
      IF(ICARD.NE.102) GO TO 99
      READ(99,5002) ICARD,TNBO,QHL,D1,TTA,TNAK
      READ(5,5002) ICARD
      IF(ICARD.NE.103) GO TO 99
      READ(99,5002) ICARD,TSS,HNF,AKNT,AKST,AKHT
      READ(5,5002) ICARD
      IF(ICARD.NE.104) GO TO 99
      READ(99,5002) ICARD,DPHITR,DPLOTR,CONV,CNT,PTRHI
      READ(5,5002) ICARD
      IF(ICARD.NE.105) GO TO 99
      READ(99,5002) ICARD,PTRLO,PMPP,DMPP,HMPP,AN1
      READ(5,5002) ICARD
      IF(ICARD.NE.106) GO TO 99
      READ(99,5002) ICARD,AN2,XL,DX,DELMPP,FXINT
      READ(5,5002) ICARD
      IF(ICARD.NE.107) GO TO 99
      READ(99,5002) ICARD,CONXP,DBAR,PHELIX,THICK,XWET
      READ(5,5002) ICARD
      IF(ICARD.NE.108) GO TO 99
      READ(99,5002) ICARD,FINTX,CONX,DROPNO,XO,XI
      READ(5,5003) ICARD
      IF(ICARD.NE.109) GO TO 99
      READ(99,5003) ICARD,DELTOT,ITABLE,JTABLE,IGEOM,PITCH1
      READ(5,5002) ICARD
      IF(ICARD.NE.110) GO TO 99
      READ(99,5002) ICARD,DBAR1,THICK1,C1,C2,WNTOTT
      PHBOO=PHBO
      THBOO=THBO
      TNBOO=TNBO
      PTRLOO=PTRLO
      PTRHII=PTRHI
      NKT=CNT
      LX=XL
      IX=XI
      JOJO=1
      RETURN
      END
      SUBROUTINE CONSTS
C     MAIN PROGRAM INPUT DATA
      COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
```

A-2

```
     1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
     2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
     3 PMPP,DMPP,HMPP,AN1,AN2,LX,
     4 DX,DELMPP,FXINT,CONXP,
     5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,X0,IX,DELTOT,
     6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
      COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
     1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
     2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
      COMMON/AC/ ACMPP
      COMMON/RR/ RR
      COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
     1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
     2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
     3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
C
C 2.0 THERMAL PASS CONSTANTS
      RB=DBAR/2.0
      R1=D1/2.
      R2=R1+TTA
      R3=R2+TNAK
      R4=R3+TSS
      D2=2.*R4
      R1M=(R2-R1)/ALOG(R2/R1)
      IF(R3.EQ.R2.AND.R4.GT.R2) GO TO 9
      IF(R3.EQ.R2.AND.R4.EQ.R2) GO TO 7
      R2M=(R3-R2)/ALOG(R3/R2)
      R3M=(R4-R3)/ALOG(R4/R3)
      GO TO 8
    9 R2M=R1M
      R3M=(R4-R3)/ALOG(R4/R3)
      GO TO 8
    7 R2M=R1M
      R3M=R1M
    8 RCNF=R1/(R4*HNF)
      RCNT=R1*(R4-R3)/(R3M*AKNT*12.)
      RCST=R1*(R3-R2)/(R2M*AKST*12.)
      RCHT=R1*(R2-R1)/(R1M*AKHT*12.)
      RR=RCNF+RCNT+RCST+RCHT
      IF(JTABLE.EQ.0) GO TO 14
      AAAA=12./(HNF*3.14159*D2*AN1)
      BBBB=(R4-R3)/(6.28318*R3M*AN1*AKNT)
      CCCC=(R3-R2)/(6.28318*R2M*AN1*AKST)
      DDDD=(R2-R1)/(6.28318*R1M*AN1*AKHT)
C
C     GEOMETRY OF SFHX
```

```
C
   14 RBAR= (R1+RB)/2.0
      TANBAR=6.28318*RBAR/PHELIX
      COSBAR=1./SQRT(1.+TANBAR**2)
      ALIN=3.14159/4.*(D1**2-DBAR**2)-(THICK*(R1-RB))/COSBAR
      PWLIN=3.14159*(D1+DBAR)+2.*(R1-RB)-2.*THICK
      DELIN=4.*ALIN/PWLIN
      OMEGA=6.28318/PHELIX
      PORTHT=6.28318*R1**2*OMEGA
      PORTHB=6.28318*RB**2*OMEGA
      ZT=6.28318*R1/SQRT(1.0+(R1*OMEGA)**2)-THICK
      ZB=6.28318*RB/SQRT(1.0+(RB*OMEGA)**2)-THICK
      THETB=6.28318/(1.0+(RB*OMEGA)**2)
      THETT=6.28318/(1.0+(R1*OMEGA)**2)
      Y=SQRT(R1**2+RB**2-2.0*R1*RB*COS((THETB-THETT)/2.0))
      PW=ZT+ZB+2.0*Y
      AH=PHELIX**2/6.28318*(SQRT(1.0+(OMEGA*R1)**2)-SQRT(1.0+
     1 (OMEGA*RB)**2))-THICK*(R1-RB)
      DEH=4.0*AH/PW
      RATIOA=AH/ALIN
      RATIOD=DEH/DELIN
      GHELIX=144.*WH/(3600.*AH*AN1)
      GLIN=144.*WH/(3600.*ALIN*AN1)
      IF(IGEOM.EQ.2) GO TO 10
      IF(IGEOM.EQ.3) GO TO 11
C
C     MPP GEOMETRY
C
      TANMPP=3.14159*D1/PMPP
      COSMPP=1./SQRT(1.+TANMPP**2)
      SINMPP=SQRT(1.-COSMPP**2)
      WIBMPP=PMPP*SINMPP
      ALAND=WIBMPP/AN2-DMPP
      ACMPP=DMPP*HMPP+.785*DMPP**2/2.
      PWET=3.14159*DMPP/2.+DMPP+2.*HMPP
      DEMPP=4.*ACMPP/PWET
      GMPP=144.*WH/(3600.*ACMPP*AN1*AN2)
      HHMPP=HMPP+DMPP/2.
      GO TO 13
C
C     SFHX1 GEOMETRY
C
   10 RB1=DBAR1/2.
      RBAR1=(R1+RB1)/2.
      TANMPP=6.28318*RBAR1/PITCH1
      COSMPP=1./SQRT(1.+TANMPP**2)
```

```
      ALIN1=3.14159/4.*(D1**2-DBAR1**2)-(THICK1*(R1-RB1))/COSMPP
      PWLIN1=3.14159*(D1+DBAR1)+2.*(R1-RB1)-2.*THICK1
      DELIN1=4.*ALIN1/PWLIN1
      OMEGA1=6.28318/PITCH1
      PORT1=6.28318*R1**2*OMEGA1
      PORTB1=6.28318*RB1**2*OMEGA1
      ZT1=6.28318*R1/SQRT(1.0+(R1*OMEGA1)**2)-THICK1
      ZB1=6.28318*RB1/SQRT(1.0+(RB1*OMEGA1)**2)-THICK1
      THETB1=6.28318/(1.0+(RB1*OMEGA1)**2)
      THETT1=6.28318/(1.0+(R1*OMEGA1)**2)
      Y1=SQRT(R1**2+RB1**2-2.0*R1*RB1*COS((THETB1-THETT1)/2.0))
      PW1=ZT1+ZB1+2.0*Y1
      ACMPP=PITCH1**2/6.28318*(SQRT(1.0+(OMEGA1*R1)**2)-
     1 SQRT(1.0+(OMEGA1*RB1)**2))-THICK1*(R1-RB1)
      DEMPP=4.*ACMPP/PW1
      ARATIO=ACMPP/ALIN1
      DRATIO=DEMPP/DELIN1
      PMPP=PITCH1
      HMPP=R1-RB1
      HHMPP=0.0
      GMPP=144.*WH/(3600.*ACMPP*AN1)
      GLNMPP=144.*WH/(3600.*ALIN1*AN1)
      DMPP=3.14159*D1/SQRT(1.+(3.14159*D1/PMPP)**2)-THICK1
      GO TO 13
C
C     PH SECTION GEOMETRY WITH WITH IGEOM=3.
C
   11 GMPP=GHELIX
      DEMPP=DEH
      COSMPP=COSBAR
      ACMPP=AH
      PMPP=PHELIX
      HMPP=R1-RB
      HHMPP=0.0
      DMPP=3.14159*D1/SQRT(1.+(3.14159*D1/PMPP)**2)-THICK
      QXPTOT=0.0
   13 RETURN
      END
      SUBROUTINE POWBAL
C     MAIN PROGRAM INPUT DATA
      COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
     1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
     2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
     3 PMPP,DMPP,HMPP,AN1,AN2,LX,
     4 DX,DELMPP,FXINT,CONXP,
     5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,XO,IX,DELTOT,
```

```
      6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
       COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
      1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
      2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
       COMMON/INPUT/ PHBOO,THBOO,TNBOO,PTRLOO,PTRHII,WNTOTT,XL,XI,CNT
       COMMON/RR/ RR
       COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
      1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
      2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
      3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
C
C 1.0 THERMAL POWER BALANCE
C
       ISTEP=1000
       IF(PHBO.NE.0.0) GO TO 4
       TEXABS=THBO+460.
       PHBO=WH*SQRT(TEXABS)/292.25714
     4 THS=THGP(PHBO,ISTEP,IER)
       HHF=HHGLT(THS,ISTEP,IER)
       HHIN=HHGLT(THBI,ISTEP,IER)
       HHFV=HHGET(THS,ISTEP,IER)
       HNIN=HNAT(TNBI,ISTEP,IER)
       DHHG=HHF-HHIN+HHFV+.025*(THBO-THS)
       QHG=WH*DHHG
       QT=QHG+3413.*QHL
       QTT=QT/3413.
       IF(TNBO.EQ.0.0) GO TO 2
       HNEX=HNAT(TNBO,ISTEP,IER)
       DHNAK=HNIN-HNEX
       WNNET=QHG/DHNAK
       WNTOT=QT/DHNAK
       IF(TNBO.GT.0.0) GO TO 3
     2 DHNAK=QT/WNTOTT
       WNNET=QHG/DHNAK
       HNEX=HNIN-DHNAK
       TNBO=TNAH(HNEX,ISTEP,IER)
       WNTOT=WNTOTT
     3 RETURN
       END
       SUBROUTINE MPPPH(NOGO)
C      MAIN PROGRAM DIMENSION STATEMENT
       COMMON/SS/PPH(75),THPH(75),TNPH(75),ALPH(75),K(75),DTPHB(75),
      1 PRPH(75),REPH(75),PEPH(75),ANUPH(75),HPH(75),UPH(75),
      2 QFPH(75),DTPHF(75),FL(75),T4PH(75),T3PH(75),T2PH(75),T1PH(75),
      3 DTTAPH(75),DTSTPH(75),DTSSPH(75),DTTOPH(75),
      1ALX(51),PX(51),TNX(51),HNX(51),X(51),KX(51),TX(51),
```

```
     2 DTXF(51),FGLIN(51),FGXTAN(51),FXGP(51),ROX(51),REX(51),
     3R1X(51),RATIO(51),FILMX(51),ANUX(51),HX(51),UX(51),
     4QFX(51),UTV(51),YFBAR(51),DROPN(51),ALAM(51),T4X(51),T3X(51),
     5 T2X(51),T1X(51),DTTAX(51),DTSTX(51),DTSSX(51),DTTOX(51),
     1 ALXP(51),PXP(51),TNXP(51),TXP(51),DTXPB(51),FLINXP(51),FTANXP(51)
     2,ROXP(51),R1XP(51),REXPGP(51),FXPGP(51),FILMXP(51),ANUXP(51),
     3 HXP(51),UXP(51),QFXP(51),DTXPF(51),XP(51),KXP(51),
     4ROMPP(51),PHIXP(51),
     5 T4XP(51),T3XP(51),T2XP(51),T1XP(51),DTTAXP(51),DTSTXP(51),
     6 DTSSXP(51),DTTOXP(51),
     1 RESH(45),FVTAN(45),
     2 KSH(45),TNSH(45),TSH(45),DTMSH(45),ANULIN(45),HLIN(45),ANUFOR(45)
     3 ,HFOR(45),HFREE(45),DTSHF(45),HSH(45),USH(45),UPSH(45),QFSH(45),
     4 FVSHLN(45),FVSH(45),PSH(45),PLSH(45),ALSH(45),T4SH(45),T3SH(45),
     5 T2SH(45),T1SH(45),DTTASH(45),DTSTSH(45),DTSSSH(45),DTTOSH(45)
C     MAIN PROGRAM INPUT DATA
      COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
     1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
     2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
     3 PMPP,DMPP,HMPP,AN1,AN2,LX,
     4 DX,DELMPP,FXINT,CONXP,
     5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,XO,IX,DELTOT,
     6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
      COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
     1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
     2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
      COMMON/AC/ACMPP
      COMMON/RR/ RR
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
     1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
     2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
     3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
C
C 3.0 MPP PREHEAT SECTION.
      NOGO=2
      TRHI=DPHITR
      TRLO=DPLOTR
      KKK=1
      GO TO 10
    6 TRHI=DPPHTR
      GO TO 12
   30 TRLO=DPPHTR
      GO TO 12
   10 PBITR=.5*(PTRHI+PTRLO)
```

```
   12 DPPHTR=.5*(TRHI+TRLO)
      PPP=PBITR-DPPHTR
      THGPP=THGP(PPP,ISTEP,IER)
      DTHGPH=THGPP-THBI
      SM=LX-1
      K(1)=1
      DDTHG=DTHGPH/SM
      PPH(1)=PBITR
      THPH(1)=THBI
      TNPH(1)=TNBO
      ALPH(1)=0.0
      QPHT=0.0
C
C     NODAL CALCULATIONS
C
      DO 50 L=2,LX
      ISTEP=3000+L
      K(L)=L
      M=L-1
      THPH(L)=THPH(M)+DDTHG
      HHGPH1=HHGLT(THPH(M),ISTEP,IER)
      HHGPH2=HHGLT(THPH(L),ISTEP,IER)
      DDHHG=HHGPH2-HHGPH1
      DQPH=WH*DDHHG
      QPHT=QPHT+DQPH
      DDHN=DQPH/WNNET
      HNPH1=HNAT(TNPH(M),ISTEP,IER)
      HNPH2=HNPH1+DDHN
      TNPH(L)=TNAH(HNPH2,ISTEP,IER)
      HBNPH=HNPH2-DDHN/2.
      TBNPH=TNAH(HBNPH,ISTEP,IER)
      TBHPH=THPH(M)+DDTHG/2.
      DTPHB(M)=TBNPH-TBHPH
      CPPH=CPHGLT(TBHPH,ISTEP,IER)
      AMUPH=VHGLT(TBHPH,ISTEP,IER)
      AKPH=CHGLT(TBHPH,ISTEP,IER)
      ROPH=RHGLT(TBHPH,ISTEP,IER)
C
C     HEAT TRANSFER CALCULATIONS
C
      PRPH(M)= CPPH*AMUPH/AKPH
      REPH(M)=300.*GMPP*DEMPP/AMUPH
      PEPH(M)=REPH(M)*PRPH(M)
      IF(REPH(M).LT.2000.) GO TO 16
      EPSRAT=EPSR1(REPH(M),ISTEP,IER)
      EE=PEPH(M)-(1.82*REPH(M))/EPSRAT**1.4
```

```
      IF(EE.GT.0.0) GO TO 15
      ANUPH(M)=7.
      GO TO 20
   16 ANUPH(M)=5.
      GO TO 20
   15 ANUPH(M)=7.+.025*EE**.8
   20 HPH(M)=12.*AKPH/DEMPP*ANUPH(M)
      UPH(M)=1.0/(RR+1.0/HPH(M))
      QFPH(M)=UPH(M)*DTPHB(M)
      DDLPH=12./(6.28318*R1*AN1)*DQPH/QFPH(M)
      DTPHF(M)=QFPH(M)/HPH(M)
      ALPH(L)=ALPH(M)+DDLPH
      FL(M)=.316/REPH(M)**.25
      DDPPH=FL(M)*DDLPH/(DEMPP*COSMPP*24.*32.2*ROPH)*GMPP**2
      PPH(L)=PPH(M)-DDPPH
      IF(JTABLE.EQ.0) GO TO 50
      T4PH(M)=TBNPH-AAAA*DQPH/DDLPH
      T3PH(M)=T4PH(M)-BBBB*DQPH/DDLPH
      T2PH(M)=T3PH(M)-CCCC*DQPH/DDLPH
      T1PH(M)=T2PH(M)-DDDD*DQPH/DDLPH
      DTTAPH(M)=T2PH(M)-T1PH(M)
      DTSTPH(M)=T3PH(M)-T2PH(M)
      DTSSPH(M)=T4PH(M)-T3PH(M)
      DTTOPH(M)=T4PH(M)-T1PH(M)
   50 CONTINUE
      QFPH(LX)=0.0
      UPH(LX)=0.0
      DTPHB(LX)=0.0
      HPH(LX)=0.0
      DTPHF(LX)=0.0
      REPH(LX)=0.0
      PRPH(LX)=0.0
      ANUPH(LX)=0.0
      PEPH(LX)=0.0
      FL(LX)=0.0
      T4PH(LX)=0.0
      T3PH(LX)=0.0
      T2PH(LX)=0.0
      T1PH(LX)=0.0
      DTTAPH(LX)=0.0
      DTSTPH(LX)=0.0
      DTSSPH(LX)=0.0
      DTTOPH(LX)=0.0
      DPPH=PBITR-PPH(LX)
      DTPP=TNPH(LX)-THPH(LX)
      DTPHT=THPH(LX)-THBI
```

```
      DLPH=ALPH(LX)
      QFPHB=12.*QPHT/(3.14159*D1*DLPH*AN1)
      IF(DPPH.LT.1.2.AND.DTPP.GT.0.0) GO TO 80
      IF(DPPH.LT.1.2.AND.DTPP.LT.0.0) GO TO 111
      IF(KKK.LT.NKT) GO TO 60
      WRITE(6,5000) DPPH
 5000 FORMAT(1H0,10X,42HMAXIMUM NO. OF ITERATIONS HAS BEEN REACHED//1X,
     1 5HDPPH=,F10.4)
      NOGO=1
      RETURN
   60 KKK=KKK+1
      TEST=(DPPH-DPPHTR)/DPPH
      IF(ABS(TEST).LT.CONV.AND.DTPP.GT.0.0) GO TO 80
      IF(DTPP) 111,111,222
  111 WRITE(6,1111) DTPP
 1111 FORMAT(1H0,20X,21HBOILING IS SUPPRESSED//1X,5HDTPP=,F10.4)
      NOGO=1
      RETURN
  222 IF(TEST)6,80,30
   80 IF(IGEOM.EQ.3) NOGO=3
      RETURN
      END
      SUBROUTINE MPPXP(IOIO)
C     MAIN PROGRAM DIMENSION STATEMENT
      COMMON/SS/PPH(75),THPH(75),TNPH(75),ALPH(75),K(75),DTPHB(75),
     1 PRPH(75),REPH(75),PEPH(75),ANUPH(75),HPH(75),UPH(75),
     2 QFPH(75),DTPHF(75),FL(75),T4PH(75),T3PH(75),T2PH(75),T1PH(75),
     3 DTTAPH(75),DTSTPH(75),DTSSPH(75),DTTOPH(75),
     1ALX(51),PX(51),TNX(51),HNX(51),X(51),KX(51),TX(51),
     2 DTXF(51),FGLIN(51),FGXTAN(51),FXGP(51),ROX(51),REX(51),
     3R1X(51),RATIO(51),FILMX(51),ANUX(51),HX(51),UX(51),
     4QFX(51),UTV(51),YFBAR(51),DROPN(51),ALAM(51),T4X(51),T3X(51),
     5 T2X(51),T1X(51),DTTAX(51),DTSTX(51),DTSSX(51),DTTOX(51),
     1 ALXP(51),PXP(51),TNXP(51),TXP(51),DTXPB(51),FLINXP(51),FTANXP(51)
     2,ROXP(51),R1XP(51),REXPGP(51),FXPGP(51),FILMXP(51),ANUXP(51),
     3 HXP(51),UXP(51),QFXP(51),DTXPF(51),XP(51),KXP(51),
     4ROMPP(51),PHIXP(51),
     5 T4XP(51),T3XP(51),T2XP(51),T1XP(51),DTTAXP(51),DTSTXP(51),
     6 DTSSXP(51),DTTOXP(51),
     1 RESH(45),FVTAN(45),
     2 KSH(45),TNSH(45),TSH(45),DTMSH(45),ANULIN(45),HLIN(45),ANUFOR(45)
     3 ,HFOR(45),HFREE(45),DTSHF(45),HSH(45),USH(45),UPSH(45),QFSH(45),
     4 FVSHLN(45),FVSH(45),PSH(45),PLSH(45),ALSH(45),T4SH(45),T3SH(45),
     5 T2SH(45),T1SH(45),DTTASH(45),DTSTSH(45),DTSSSH(45),DTTOSH(45)
C     MAIN PROGRAM INPUT DATA
      COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
```

```
     1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
     2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
     3 PMPP,DMPP,HMPP,AN1,AN2,LX,
     4 DX,DELMPP,FXINT,CONXP,
     5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,X0,IX,DELTOT,
     6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
      COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
     1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
     2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
      COMMON/IMAX/ IMAX
      COMMON/AC/ACMPP
      COMMON/RR/ RR
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      COMMON/ROPRIM/BETA,RORO
      COMMON/ROXP/ AMUXPF,AMUXPV
      COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
     1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
     2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
     3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
      DATA KOUNT/0/
      EXTERNAL RPROOT
      EXTERNAL XPROOT
C
C 4.0 MPP VAPOR QUALITY SECTION
      KOUNT=KOUNT+1
      IOIO=1
      IF(IGEOM.NE.1) GO TO 98
      DDD=DMPP/COSMPP
      PWLMPP=DDD+2.*HMPP+(3.14159*DDD)/2.0
      ACLMPP=ACMPP/COSMPP
      DELIXP=4.*ACLMPP/PWLMPP
      BETA=DMPP/R1
      RRO2=R1-HMPP
      RORO=RRO2/R1
C     MPPXP SECTION INLET BOUNDARY CONDITIONS
   98 KXP(1)=1
      ALXP(1)= ALPH(LX)
      PXP(1)=PPH(LX)
      TNXP(1)=TNPH(LX)
      HNXP=HNAT(TNXP(1),ISTEP,IER)
      QXPTOT   =0.0
      XP(1)=0.0
C
C     NODAL CALCULATIONS
C
```

```
C     THERMAL STATE AND HG PROPERTIES
      DO 100  I=2,51
      ISTEP=4000+I
      KXP(I)=I
      IMAX=I
      J=I-1
      XP(I)=XP(J)+DX
      XBAR=XP(I)-DX/2.0
      TXP(J)=THGP(PXP(J),ISTEP,IER)
      TXPB=TXP(J)
      ROXPF=RHGLT(TXPB,ISTEP,IER)
      ROXPV=RHGGT(TXPB,ISTEP,IER)
      AMUXPF=VHGLT(TXPB,ISTEP,IER)
      AMUXPV=VHGGT(TXPB,ISTEP,IER)
      AKXPF=CHGLT(TXPB,ISTEP,IER)
      AKXPV=CHGGT(TXPB,ISTEP,IER)
      HFXPV=HHGET(TXPB,ISTEP,IER)
      QXP    =DX*WH*HFXPV
      QXPTOT    =QXPTOT    +QXP
      DHNXP=QXP    /WNNET
      HNXP=HNXP+DHNXP
      TNXP(I)=TNAH(HNXP,ISTEP,IER)
      HNXPB=HNXP-DHNXP/2.0
      TNXPB=TNAH(HNXPB,ISTEP,IER)
      DTXPB(J)=TNXPB-TXPB
C
C     VISCOUS-TURBULENT TWO PHASE FLOW. LIQUID FILM AT WALL.
C
C     TWO PHASE  PRESSURE  DROP CORRELATION
      XXX(J)=XBAR/(1.-XBAR)*ROXPF/ROXPV*AMUXPV/AMUXPF
      YYY(J)=R1*AMUXPV/(12.*XBAR*WH)*AN1*AN2
      IF(IGEOM.NE.1) GO TO 97
      RPHI=1.
      RPLO=0.9
      TNIXF=FXINT
      CALL ROOT(RPROOT,RPLO,RPHI,0.001,20,ISTEP,ROMPP(J),IERR)
      R1XP(J)=ROMPP(J)*R1
C     LIQUID FILM THICKNESS
      FILMXP(J)=R1-R1XP(J)
C
      GXPMPP=XBAR*GMPP
      REXPGP(J)=300.*GXPMPP*DEMPP/AMUXPV
      FXPGP(J)=.316/(REXPGP(J)**.25)
      DPDXGS=FXPGP(J)*GXPMPP**2/(DEMPP*COSMPP*24.*32.2*ROXPV)
      SS=(BETA*R1XP(J)+2.*(R1XP(J)-RRO2)+.5*3.14159*BETA*RRO2)/
     1 (BETA*R1+2.*(R1-RRO2)+.5*3.14159*BETA*RRO2)
```

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      SSS=(((R1**2-RRO2**2)*BETA*0.5+3.14159/8.*(BETA*RRO2)**2)/
     1 ((R1XP(J)**2-RRO2** 2)*BETA*0.5+3.14159/8.*(BETA*RRO2)**2))**3
      PHIXP(J)=FXINT/FXPGP(J)*SS*SSS
      GO TO 96
   97 GXPMPP=XBAR*GMPP
      REXPGP(J)=300.*GXPMPP*DEMPP/AMUXPV
      FLINXP(J)=(.316/(REXPGP(J)**.25)*ARATIO**1.75*DRATIO**1.25)
     1 *COSMPP*C1
      FTANXP(J)=(.0584*(3.14159*D1/PITCH1)**3*(D1-THICK1)/(D1+DBAR1)
     1 *ARATIO**2*DRATIO)*COSMPP*C1
      FXPGP(J)= FLINXP(J)+FTANXP(J)
      DPDXGS=FXPGP(J)*GXPMPP**2/(DEMPP*COSMPP*24.*32.2*ROXPV)
      RPHI=1.0
      RPLO=0.375
      TNIXF=FXINT
      CALL ROOT(XPROOT,RPLO,RPHI,0.001,20,ISTEP,ROMPP(J),IERR)
      R1XP(J)=ROMPP(J)*R1
      Z=(R1/R1XP(J))**5
      ZZ=(R1XP(J)**2-R1**2)*R1XP(J)**2
      ZZZ=-0.5*(R1**4-R1XP(J)**4)+R1*(R1**2-R1XP(J)**2)
      PHIXP(J)=FXINT/FXPGP(J)*Z*(1.0+ROXPV/ROXPF*ZZ/ZZZ*(1.0-XBAR)/
     1 XBAR)**2
      FILMXP(J)=R1-R1XP(J)
C     HEAT TRANSFER
   96 ANUXP(J)=CONXP*D1/FILMXP(J)
      HXP(J)=ANUXP(J)*12.0*AKXPF/D1
      UXP(J)=1.0/(RR+1.0/HXP(J))
      QFXP(J)=UXP(J)*DTXPB(J)
      DDLXP=12.0/(6.28318*R1*AN1)*QXP    /QFXP(J)
      DTXPF(J)=QFXP(J)/HXP(J)
      ALXP(I)=ALXP(J)+DDLXP
      IF(JTABLE.EQ.0) GO TO 95
      T4XP(J)=TNXPB-AAAA*QXP/DDLXP
      T3XP(J)=T4XP(J)-BBBB*QXP/DDLXP
      T2XP(J)=T3XP(J)-CCCC*QXP/DDLXP
      T1XP(J)=T2XP(J)-DDDD*QXP/DDLXP
      DTTAXP(J)=T2XP(J)-T1XP(J)
      DTSTXP(J)=T3XP(J)-T2XP(J)
      DTSSXP(J)=T4XP(J)-T3XP(J)
      DTTOXP(J)=T4XP(J)-T1XP(J)
   95 IF(XP(I).EQ.0.12.AND.DELMPP.EQ.0.0) GO TO 11
      IF(DELMPP.EQ.0.0) GO TO 101
      IF(DELMPP-ALXP(I)) 99,11,101
   99 S=DELMPP-ALXP(J)
      ALXP(I)=ALXP(J)+S
      XP(I)=XP(J)+DX*S/DDLXP
```

```
      QXPTOT=QXPTOT-QXP
      DDXP=DX*S/DDLXP
      QXP=DDXP*HFXPV*WH
      QXPTOT    =QXPTOT    +QXP
      DDPXP=PHIXP(J)*DPDXGS*S
      GO TO 13
   11 DDPXP=PHIXP(J)*DPDXGS*DDLXP
   13 PXP(I)=PXP(J)-DDPXP
      IF(PXP(I).LE.PHBO+3.) GO TO 199
      TXP(I)=THGP(PXP(I),ISTEP,IER)
      GO TO 12
  101 DDPXP=PHIXP(J)*DPDXGS*DDLXP
      PXP(I)=PXP(J)-DDPXP
      IF(PXP(I).LE.PHBO+3.) GO TO 199
      TXP(I)=THGP(PXP(I),ISTEP,IER)
  100 CONTINUE
   12 DLXPT=ALXP(IMAX)-ALXP(1)
      DPXPT=PXP(1)-PXP(IMAX)
      QFXPB=12.*QXPTOT/(3.14159*D1*DLXPT*AN1)
      QFXP(IMAX)=0.0
      UXP(IMAX)=0.0
      DTXPB(IMAX)=0.0
      HXP(IMAX)=0.0
      DTXPF(IMAX)=0.0
      ANUXP(IMAX)=0.0
      XXX(IMAX)=0.0
      YYY(IMAX)=0.0
      PHIXP(IMAX)=0.0
      FXPGP(IMAX)=0.0
      ROMPP(IMAX)=0.0
      FILMXP(IMAX)=0.0
      REXPGP(IMAX)=0.0
      T4XP(IMAX)=0.0
      T3XP(IMAX)=0.0
      T2XP(IMAX)=0.0
      T1XP(IMAX)=0.0
      DTTAXP(IMAX)=0.0
      DTSTXP(IMAX)=0.0
      DTSSXP(IMAX)=0.0
      DTTOXP(IMAX)=0.0
      RETURN
  199 PTRLO=PBITR
      IOIO=2
      IF(KOUNT.LT.100) RETURN
      WRITE(6,1000)
 1000 FORMAT('1','PXP IS LESS THAN PHBO IN MPPXP AFTER 100 TRIES CASE SK
```

```
      *IPPED')
       IOIO=3
       RETURN
       END
       SUBROUTINE SFHXX
C      MAIN PROGRAM DIMENSION STATEMENT
       COMMON/SS/PPH(75),THPH(75),TNPH(75),ALPH(75),K(75),DTPHB(75),
      1 PRPH(75),REPH(75),PEPH(75),ANUPH(75),HPH(75),UPH(75),
      2 QFPH(75),DTPHF(75),FL(75),T4PH(75),T3PH(75),T2PH(75),T1PH(75),
      3 DTTAPH(75),DTSTPH(75),DTSSPH(75),DTTOPH(75),
      1ALX(51),PX(51),TNX(51),HNX(51),X(51),KX(51),TX(51),
      2 DTXF(51),FGLIN(51),FGXTAN(51),FXGP(51),ROX(51),REX(51),
      3R1X(51),RATIO(51),FILMX(51),ANUX(51),HX(51),UX(51),
      4QFX(51),UTV(51),YFBAR(51),DROPN(51),ALAM(51),T4X(51),T3X(51),
      5 T2X(51),T1X(51),DTTAX(51),DTSTX(51),DTSSX(51),DTTOX(51),
      1 ALXP(51),PXP(51),TNXP(51),TXP(51),DTXPB(51),FLINXP(51),FTANXP(51)
      2,ROXP(51),R1XP(51),REXPGP(51),FXPGP(51),FILMXP(51),ANUXP(51),
      3 HXP(51),UXP(51),QFXP(51),DTXPF(51),XP(51),KXP(51),
      4ROMPP(51),PHIXP(51),
      5 T4XP(51),T3XP(51),T2XP(51),T1XP(51),DTTAXP(51),DTSTXP(51),
      6 DTSSXP(51),DTTOXP(51),
      1 RESH(45),FVTAN(45),
      2 KSH(45),TNSH(45),TSH(45),DTMSH(45),ANULIN(45),HLIN(45),ANUFOR(45)
      3 ,HFOR(45),HFREE(45),DTSHF(45),HSH(45),USH(45),UPSH(45),QFSH(45),
      4 FVSHLN(45),FVSH(45),PSH(45),PLSH(45),ALSH(45),T4SH(45),T3SH(45),
      5 T2SH(45),T1SH(45),DTTASH(45),DTSTSH(45),DTSSSH(45),DTTOSH(45)
C      MAIN PROGRAM INPUT DATA
       COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
      1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
      2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
      3 PMPP,DMPP,HMPP,AN1,AN2,LX,
      4 DX,DELMPP,FXINT,CONXP,
      5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,XO,IX,DELTOT,
      6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
       COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
      1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
      2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
       COMMON/IMAX/ IMAX
       COMMON/NMAX/ NMAX
       COMMON/RR/ RR
       COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
      1  DTXB(51),NN,XTNIF
       COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
      1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
      2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
      3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
```

```
      DIMENSION ABSC(40),ORD(40)
      DATA ABSC/.01,.015,.02,.03,.04,.05,.06,.07,.08,.09,
     *          .1,.2,.3,.4,.5,.6,.7,.8,.9,1.0,
     *          2.,3.,4.,5.,6.,7.,8.,9.,10.,20.,
     *          30.,40.,50.,60.,70.,80.,90.,100.,0.0/
      DATA ORD/1.0,1.0,1.0,1.01,1.10,1.15,1.20,1.25,1.30,1.34,
     *          1.4,1.73,2.05,2.30,2.60,2.90,3.20,3.26,3.90,4.20,
     *          8.2,13.0,18.8,25.5,33.0,41.0,50.0,60.0,70.0,182.0,
     *          340.,540.,725.,1160.,1600.,2050.,2650.,3200.,0.0/
      COMMON/DLTF/CCC
      COMMON/RHO/AMUXF,AMUXV,NK
C
C 5.0 SFHX VAPOR QUALITY SECTION
C
      EXTERNAL TFROOT
      EXTERNAL ROROOT
C
C     ENTRANCE CONDITIONS
C
      KX(1)=1
      IF(IGEOM.EQ.3) GO TO 299
      ALX(1)=ALXP(IMAX)
      PX(1)=PXP(IMAX)
      TNX(1)=TNXP(IMAX)
      HNX(1)=HNAT(TNX(1),ISTEP,IER)
      QXTOT   =0.0
      X(1)=XP(IMAX)
      GO TO 300
  299 ALX(1)=ALPH(LX)
      PX(1)=PPH(LX)
      TNX(1)=TNPH(LX)
      HNX(1)=HNAT(TNX(1),ISTEP,IER)
      QXTOT=0.0
      X(1)=0.0
C     NODAL CALCULATION
C     THERMAL STATE AND HG PROPERTIES
  300 DO 222 N=2,51
      ISTEP=5000+N
      KX(N)=N
      NMAX=N
      NN=N-1
      NK=NN
      X(N)=X(NN)+DX
      IF(X(N).GE.0.99) X(N)=1.0
      IF(X(N)-1.0) 100,100,226
  100 XBAR=X(N)-DX/2.0
```

```
      TX(NN)=THGP(PX(NN),ISTEP,IER)
      TXB=TX(NN)
      ROXF=RHGLT(TXB,ISTEP,IER)
      ROXV=RHGGT(TXB,ISTEP,IER)
      AMUXF=VHGLT(TXB,ISTEP,IER)
      AMUXV=VHGGT(TXB,ISTEP,IER)
      AKXF=CHGLT(TXB,ISTEP,IER)
      AKXV=CHGGT(TXB,ISTEP,IER)
      HFXV=HHGET(TXB,ISTEP,IER)
      QX     =DX*WH*HFXV
      DHNX=QX     /WNNET
      HNX(N)=HNX(NN)+DHNX
      TNX(N)=TNAH(HNX(N),ISTEP,IER)
      HNXB=HNX(N)-DHNX/2.0
      TNXB=TNAH(HNXB,ISTEP,IER)
      DTXB(NN)=TNXB-TXB
      REX(NN)=300.*XBAR*GHELIX*DEH/AMUXV
      FGLIN(NN)=(.316/(REX(NN)**.25)*RATIOA**1.75*RATIOD**1.25)
     1 *COSBAR*C2
      FGXTAN(NN)=(.0584*(3.14159*D1/PHELIX)**3*(D1-THICK)/(D1+DBAR)*
     1 RATIOA**2*RATIOD)*COSBAR*C2
      FXGP(NN)= FGLIN(NN)+FGXTAN(NN)
      GXGP=GHELIX*XBAR
      DPDXGP=FXGP(NN)*GXGP**2/(DEH*COSBAR*24.*32.2*ROXV)
      IF(XBAR.GT.XWET) GO TO 223
C     LAMINAR-TURBULENT TWO PHASE FLOW WITH PHASE SEPARATION
      XX(NN)=XBAR/(1.0-XBAR)*ROXF/ROXV*AMUXV/AMUXF
      YY(NN)=D1*AMUXV/(12.0*2.0*XBAR*WH)*AN1
      ROLO=0.5
      ROHI=1.
      XTNIF=FINTX
      CALL ROOT(ROROOT,ROLO,ROHI,0.001,20,ISTEP,ROX(NN),IERR)
      R1X(NN)=ROX(NN)*R1
      Z=(R1/R1X(NN))**5
      ZZ=(R1X(NN)**2-R1**2)*R1X(NN)**2
      ZZZ=-0.5*(R1**4-R1X(NN)**4)+R1*(R1*2-R1X(NN)**2)
      RATIO(NN)=FINTX/FXGP(NN)*Z*(1.0+ROXV/ROXF*ZZ/ZZZ*
     1 (1.0-XBAR)/XBAR)**2
      DPDXGP=FXGP(NN)*GXGP**2/(DEH*COSBAR*24.*32.2*ROXV)
      FILMX(NN)=R1-R1X(NN)
      ANUX(NN)=CONX*D1/FILMX(NN)
      HX(NN)=ANUX(NN)*12.*AKXF/DEH
      UX(NN)=1.0/(RR+1.0/HX(NN))
      QFX(NN)=UX(NN)*DTXB(NN)
      DTXF(NN)=QFX(NN)/HX(NN)
      DDLX=12./(6.28318*R1*AN1)*QX     /QFX(NN)
```

```
      DDPX=RATIO(NN)*DPDXGP*DDLX
      GO TO 224
C     DRYWALL BOILING
  223 GXLIN=GLIN*XBAR
      UTV(NN)=GXLIN/ROXV*3.14159*D1/PHELIX
      YFBAR(NN)=(1.-XBAR)/(1.+(ROXF/ROXV-1.)*XBAR)
      BB=AKXV/(HFXV*ROXV**0.5*ROXF**0.5*UTV(NN)**3)*32.2/3600.
      DROPN(NN)=DROPNO*XO/XBAR
      AA=(1.0/(8.0*DROPN(NN))*YFBAR(NN))**.533
      CCC=12.*AKXV/DEH*6.6*DROPN(NN)*AA/(BB**0.4)
      TFLO=0.01
      TFHI=500.
      CALL ROOT(TFROOT,TFLO,TFHI,0.001,20,ISTEP,DTXF(NN),IERR)
      HX(NN)=CCC/DTXF(NN)**0.4
      ANUX(NN)=HX(NN)*DEH/(12.*AKXV)
      UX(NN)=1.0/(RR+1.0/HX(NN))
      QFX(NN)=UX(NN)*DTXB(NN)
      DDLX=12./(6.28318*R1*AN1)*QX     /QFX(NN)
      ALAM(NN)=(AMUXF/AMUXV)**0.1*(ROXV/ROXF)**0.5*(1.-XBAR)/XBAR
      AMARTI=SQRT(ALAM(NN))
      CALL=INT4(ABSC,ORD,AMARTI,PHIX)
      RATIO(NN)=PHIX**2
      DDPX=RATIO(NN)*DPDXGP*DDLX
      XX(NN)=0.0
      YY(NN)=0.0
      ROX(NN)=0.0
      FILMX(NN)=0.0
  224 ALX(N)=ALX(NN)+DDLX
      PX(N)=PX(NN)-DDPX
      TX(N)=THGP(PX(N), ISTEP,IER)
      QXTOT    =QXTOT     +QX
      IF(JTABLE.EQ.0) GO TO 227
      T4X(NN)=TNXB-AAAA*QX/DDLX
      T3X(NN)=T4X(NN)-BBBB*QX/DDLX
      T2X(NN)=T3X(NN)-CCCC*QX/DDLX
      T1X(NN)=T2X(NN)-DDDD*QX/DDLX
      DTTAX(NN)=T2X(NN)-T1X(NN)
      DTSTX(NN)=T3X(NN)-T2X(NN)
      DTSSX(NN)=T4X(NN)-T3X(NN)
      DTTOX(NN)=T4X(NN)-T1X(NN)
  227 IF(1.00-X(N)) 226,225,222
  226 DDX=1.00-X(NN)
      X(N)=X(NN)+DDX
      QXTOT=QXTOT-QX
      QX     =DDX*HFXV*WH
      QXTOT    =QXTOT     +QX
```

```
      DDLX=DDLX*DDX/DX
      DDPX=DDPX*DDX/DX
      PX(N)=PX(NN)-DDPX
      TX(N)=THGP(PX(N),ISTEP,IER)
      DHNX=QX     /WNNET
      HNX(N)=HNX(NN)+DHNX
      TNX(N)=TNAH(HNX(N),ISTEP,IER)
      ALX(N)=ALX(NN)+DDLX
      GO TO 225
  222 CONTINUE
  225 ALXTOT=ALX(NMAX)-ALX(1)
      DPXTOT=PX(1)-PX(NMAX)
      QFXB=12.*QXTOT/(3.14159*D1*ALXTOT*AN1)
      QFX(NMAX)=0.0
      UX(NMAX)=0.0
      DTXB(NMAX)=0.0
      HX(NMAX)=0.0
      DTXF(NMAX)=0.0
      ANUX(NMAX)=0.0
      XX(NMAX)=0.0
      YY(NMAX)=0.0
      RATIO(NMAX)=0.0
      FXGP(NMAX)=0.0
      FGLIN(NMAX)=0.0
      FGXTAN(NMAX)=0.0
      ROX(NMAX)=0.0
      FILMX(NMAX)=0.0
      REX(NMAX)=0.0
      T4X(NMAX)=0.0
      T3X(NMAX)=0.0
      T2X(NMAX)=0.0
      T1X(NMAX)=0.0
      DTTAX(NMAX)=0.0
      DTSTX(NMAX)=0.0
      DTSSX(NMAX)=0.0
      DTTOX(NMAX)=0.0
      RETURN
      END
      SUBROUTINE SFHXSH(NONO)
C 6.0 SUPERHEAT SECTION.
      COMMON/SS/PPH(75),THPH(75),TNPH(75),ALPH(75),K(75),DTPHB(75),
     1 PRPH(75),REPH(75),PEPH(75),ANUPH(75),HPH(75),UPH(75),
     2 QFPH(75),DTPHF(75),FL(75),T4PH(75),T3PH(75),T2PH(75),T1PH(75),
     3 DTTAPH(75),DTSTPH(75),DTSSPH(75),DTTOPH(75),
     1ALX(51),PX(51),TNX(51),HNX(51),X(51),KX(51),TX(51),
     2 DTXF(51),FGLIN(51),FGXTAN(51),FXGP(51),ROX(51),REX(51),
```

```
     3R1X(51),RATIO(51),FILMX(51),ANUX(51),HX(51),UX(51),
     4QFX(51),UTV(51),YFBAR(51),DROPN(51),ALAM(51),T4X(51),T3X(51),
     5 T2X(51),T1X(51),DTTAX(51),DTSTX(51),DTSSX(51),DTTOX(51),
     1 ALXP(51),PXP(51),TNXP(51),TXP(51),DTXPB(51),FLINXP(51),FTANXP(51)
     2,ROXP(51),R1XP(51),REXPGP(51),FXPGP(51),FILMXP(51),ANUXP(51),
     3 HXP(51),UXP(51),QFXP(51),DTXPF(51),XP(51),KXP(51),
     4ROMPP(51),PHIXP(51),
     5 T4XP(51),T3XP(51),T2XP(51),T1XP(51),DTTAXP(51),DTSTXP(51),
     6 DTSSXP(51),DTTOXP(51),
     1 RESH(45),FVTAN(45),
     2 KSH(45),TNSH(45),TSH(45),DTMSH(45),ANULIN(45),HLIN(45),ANUFOR(45)
     3 ,HFOR(45),HFREE(45),DTSHF(45),HSH(45),USH(45),UPSH(45),QFSH(45),
     4 FVSHLN(45),FVSH(45),PSH(45),PLSH(45),ALSH(45),T4SH(45),T3SH(45),
     5 T2SH(45),T1SH(45),DTTASH(45),DTSTSH(45),DTSSSH(45),DTTOSH(45)
      COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
     1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
     2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
     3 PMPP,DMPP,HMPP,AN1,AN2,LX,
     4 DX,DELMPP,FXINT,CONXP,
     5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,X0,IX,DELTOT,
     6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
      COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
     1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
     2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
      COMMON/NMAX/ NMAX
      COMMON/RR/ RR
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      COMMON/ITER/ITER
      COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
     1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
     2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
     3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
      EXTERNAL SHROOT
      COMMON/SHSH/GCON1,GCON2,GSHB
      DETAN=2.*PHELIX*(R1-RB)/(PHELIX+R1-RB)
C     ENTRANCE CONDITIONS
      KSH(1)=1
      ALSH(1)=ALX(NMAX)
      TNSH(1)=TNX(NMAX)
      PSH(1)=PX(NMAX)
      TSH(1)=TX(NMAX)
      DPSH=0.0
      DHHGSH=.025*(THBO-TSH(1))
      QSH=DHHGSH*WH
      DHNSHT=QSH/WNNET
```

```
      N4=2
      N5=IX
      DNOM=N5-1
      DQSH=WNNET*DHNSHT/DNOM
      DDHN=DQSH/WNNET
      DDTSH=DQSH/(.025*WH)
C     NODAL CALCULATIONS
      DO 1200 I=N4,N5
      ISTEP=6000+I
      II=I-1
      KSH(I)=I
      HNSH1=HNAT(TNSH(II),ISTEP,IER)
      HNSH2=HNSH1+DDHN
      TNSH(I)=TNAH(HNSH2,ISTEP,IER)
      TSH(I)=TSH(II)+DDTSH
      HNSHB=HNSH1+0.5*DDHN
      TNSHB=TNAH(HNSHB,ISTEP,IER)
      TSHB=TSH(II)+DDTSH/2.0
      DTMSH(II)=TNSHB-TSHB
      AMUSH=VHGGT(TSHB,ISTEP,IER)
      CPSH=CPHGGT(TSHB,ISTEP,IER)
      AKSH=CHGGT(TSHB,ISTEP,IER)
      ROSH=18.7*PSH(II)/(TSHB+460.0)
      RESHLN=300.*GLIN*DELIN/AMUSH
      RESH(II)=300.*GHELIX*DEH/AMUSH
      PRSH=CPSH*AMUSH/AKSH
      ANULIN(II)=0.023*RESHLN**0.8*PRSH**0.4
      HLIN(II)=12.*AKSH*ANULIN(II)/DELIN
      ANURAO=(1.0+(3.14159*D1/PHELIX)**2)**.4*RATIOD**.8
      ANUFOR(II)=ANURAO*ANULIN(II)
      HFOR(II)=12.0*AKSH*ANUFOR(II)/DEH
      FREE=12.*AKSH/DETAN*ANULIN(II)*7.1*(1.0/(TSHB+460.))**.3333/
     1 (RESHLN**.13*PRSH**.07)*(3.14159*D1/PHELIX)**.6667*
     2 (DETAN/DELIN)**.6667
      GSHB=DTMSH(II)
      GCON1=RR*FREE
      GCON2=(RR*HFOR(II)+1.0)/(FREE*RR)
      DTSHHI=500.
      DTSHLO=0.01
      CALL ROOT(SHROOT,DTSHLO,DTSHHI,0.001,20,ISTEP,DTSHF(II),IERR)
      HFREE(II)=FREE*DTSHF(II)**.3333
      HSH(II)=HFOR(II)+HFREE(II)
      USH(II)=1.0/(RR+1.0/HSH(II))
      QFSH(II)=USH(II)*DTMSH(II)
      DDLSH=12./(3.14159*D1*AN1)*DQSH/QFSH(II)
      FVSHLN(II)=(.316/(RESH(II)**.25)*RATIOA**1.75*RATIOD**1.25)
```

```
     1 *COSBAR*C2
      FVTAN(II)=(.0584*(3.14159*D1/PHELIX)**3*(D1-THICK)/(D1+DBAR)*
     1 RATIOA**2*RATIOD)*COSBAR*C2
      FVSH(II)= FVSHLN(II)+FVTAN(II)
      DDPSH=FVSH(II)*DDLSH/(COSBAR*DEH*24.*32.2*ROSH)*GHELIX**2
      PSH(I)=PSH(II)-DDPSH
      DPSH=DPSH+DDPSH
      ALSH(I)=ALSH(II)+DDLSH
      IF(JTABLE.EQ.0) GO TO 1200
      T4SH(II)=TNSHB-AAAA*DQSH/DDLSH
      T3SH(II)=T4SH(II)-BBBB*DQSH/DDLSH
      T2SH(II)=T3SH(II)-CCCC*DQSH/DDLSH
      T1SH(II)=T2SH(II)-DDDD*DQSH/DDLSH
      DTTASH(II)=T2SH(II)-T1SH(II)
      DTSTSH(II)=T3SH(II)-T2SH(II)
      DTSSSH(II)=T4SH(II)-T3SH(II)
      DTTOSH(II)=T4SH(II)-T1SH(II)
 1200 CONTINUE
      QFSH(IX)=0.0
      USH(IX)=0.0
      DTMSH(IX)=0.0
      HSH(IX)=0.0
      DTSHF(IX)=0.0
      RESH(IX)=0.0
      ANULIN(IX)=0.0
      HLIN(IX)=0.0
      ANUFOR(IX)=0.0
      HFOR(IX)=0.0
      FVSH(IX)=0.0
      FVSHLN(IX)=0.0
      FVTAN(IX)=0.0
      T4SH(IX)=0.0
      T3SH(IX)=0.0
      T2SH(IX)=0.0
      T1SH(IX)=0.0
      DTTASH(IX)=0.0
      DTSTSH(IX)=0.0
      DTSSSH(IX)=0.0
      DTTOSH(IX)=0.0
      IF(DELTOT.EQ.0.0) GO TO 1275
      IF(DELTOT-ALSH(IX)) 1274,1275,1276
 1274 WRITE(6,2222)
 2222 FORMAT(1H0,20X,19HDELTOT IS TOO SHORT)
      GO TO 1275
 1276 ESHL=DELTOT-ALSH(IX)
      DPESH=FVSH(IX-1)*ESHL/(COSBAR*DEH*24.*32.2*ROSH)*GHELIX**2
```

```
      GO TO 1277
 1275 ESHL=0.0
      DPESH=0.0
 1277 DTSHT=TSH(IX)-TSH(1)
      ALSHT=ALSH(IX)-ALSH(1)
      DPSHT=PSH(1)-PSH(IX)
      PEXIT=PSH(IX)-DPESH
      ALONGT=ALSH(IX)+ESHL
      IF(ITER.GE.NKT) GO TO 444
      ITER=ITER+1
      TEST1=PEXIT-PHBO
      CONV1=2.0
      IF(ABS(TEST1).LE.CONV1) GO TO 4
      IF(TEST1) 2,4,3
    2 PTRLO=PBITR
      NONO=1
      RETURN
    3 PTRHI=PBITR
      NONO=1
      RETURN
  444 WRITE(6,4444) PEXIT
 4444 FORMAT(1H0,10X,38HMAXIMUM OF ITERATIONS HAS BEEN REACHED//
     1 6HPEXIT=,F10.4)
    4 THBO=TSH(IX)
      PHBO=PEXIT
      DPTOT=PPH(1)-PEXIT
      QSHB=QSH/(3.14159*D1*ALSHT*AN1)*12.
      QTOT=QPHT+QXPTOT+QXTOT+QSH
      DHNAK=QTOT/WNNET
      DHHG=QTOT/WH
      QKW=WNTOT*DHNAK/3413.
      DTTERM=TNSH(IX)-TSH(IX)
      TSAEX=THGP(PEXIT,ISTEP,IER)
      DTSHEX=TSH(IX)-TSAEX
      NONO=2
      RETURN
      END
      SUBROUTINE OUTPUT
C     MAIN PROGRAM DIMENSION STATEMENT
      COMMON/SS/PPH(75),THPH(75),TNPH(75),ALPH(75),K(75),DTPHB(75),
     1 PRPH(75),REPH(75),PEPH(75),ANUPH(75),HPH(75),UPH(75),
     2 QFPH(75),DTPHF(75),FL(75),T4PH(75),T3PH(75),T2PH(75),T1PH(75),
     3 DTTAPH(75),DTSTPH(75),DTSSPH(75),DTTOPH(75),
     1ALX(51),PX(51),TNX(51),HNX(51),X(51),KX(51),TX(51),
     2 DTXF(51),FGLIN(51),FGXTAN(51),FXGP(51),ROX(51),REX(51),
     3R1X(51),RATIO(51),FILMX(51),ANUX(51),HX(51),UX(51),
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     4QFX(51),UTV(51),YFBAR(51),DROPN(51),ALAM(51),T4X(51),T3X(51),
     5 T2X(51),T1X(51),DTTAX(51),DTSTX(51),DTSSX(51),DTTOX(51),
     1 ALXP(51),PXP(51),TNXP(51),TXP(51),DTXPB(51),FLINXP(51),FTANXP(51)
     2,ROXP(51),R1XP(51),REXPGP(51),FXPGP(51),FILMXP(51),ANUXP(51),
     3 HXP(51),UXP(51),QFXP(51),DTXPF(51),XP(51),KXP(51),
     4ROMPP(51),PHIXP(51),
     5 T4XP(51),T3XP(51),T2XP(51),T1XP(51),DTTAXP(51),DTSTXP(51),
     6 DTSSXP(51),DTTOXP(51),
     1 RESH(45),FVTAN(45),
     2 KSH(45),TNSH(45),TSH(45),DTMSH(45),ANULIN(45),HLIN(45),ANUFOR(45)
     3 ,HFOR(45),HFREE(45),DTSHF(45),HSH(45),USH(45),UPSH(45),QFSH(45),
     4 FVSHLN(45),FVSH(45),PSH(45),PLSH(45),ALSH(45),T4SH(45),T3SH(45),
     5 T2SH(45),T1SH(45),DTTASH(45),DTSTSH(45),DTSSSH(45),DTTOSH(45)
C     MAIN PROGRAM INPUT DATA
      COMMON/DATA/ WH,PHBO,THBI,THBO,TNBI,TNBO,QHL,
     1 D1,TTA,TNAK,TSS,HNF,AKNT,AKST,AKHT,
     2 DPHITR,DPLOTR,CONV,NKT,PTRHI,PTRLO,
     3 PMPP,DMPP,HMPP,AN1,AN2,LX,
     4 DX,DELMPP,FXINT,CONXP,
     5 DBAR,PHELIX,THICK,XWET,FINTX,CONX,DROPNO,XO,IX,DELTOT,
     6 DATE(2),COMENT(18),ITABLE,JTABLE,IGEOM,PITCH1,DBAR1,THICK1,C1,C2
      COMMON/VALUE/ WNNET,RB,R1,GMPP,DEMPP,TANMPP,COSMPP,GLIN,DELIN,
     1 RATIOD,DEH,COSBAR,GHELIX,PBITR,AAAA,BBBB,CCCC ,DDDD,RATIOA,
     2 ARATIO,DHNAK,DHHG,DTPP,DTTERM,DTSHEX,HNEX,DRATIO,HHIN
      COMMON/AC/ACMPP
      COMMON/RR/ RR
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      COMMON/DAOUT/ DLPH,DPPH,QFPHB,QPHT,DLXPT,DPXPT,QFXPB,QXPTOT,
     1              ALXTOT,DPXTOT,QFXB,QXTOT,ALSHT,DPSHT,QSHB,QSH,
     2              ESHL,DPESH,ALONGT,DPTOT,PEXIT,QTOT,
     3              WNTOT,QKW, RCNF,RCNT,RCST,RCHT,D2,HHMPP,AH
      COMMON/IMAX/ IMAX
      COMMON/NMAX/ NMAX
      COMMON/INPUT/ PHBOO,THBOO,TNBOO,PTRLOO,PTRHII,WNTOTT,XL,XI,CNT
C
C     PRINTOUT OF RESULTS
C
      IPAGE=1
      WRITE(6,1000) IPAGE,DATE,COMENT
      WRITE(6,1001)
      WRITE(6,1002) DLPH,PPH(1),DPPH,QFPHB,TNPH(1),THPH(1),GMPP,QPHT
      IF(IGEOM.EQ.3) GO TO 7000
      WRITE(6,1003) DLXPT,PXP(1),DPXPT,QFXPB,TNXP(1),TXP(1),GMPP,QXPTOT,
     1              XP(IMAX)
 7000 WRITE(6,1004) ALXTOT,PX(1),DPXTOT,QFXB,TNX(1),TX(1),GHELIX,QXTOT
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      WRITE(6,1005) ALSHT,PSH(1),DPSHT,QSHB,TNSH(1),TSH(1),GHELIX,QSH
      WRITE(6,1006) ESHL,PSH(IX),DPESH,TNSH(IX),TSH(IX),GHELIX
      WRITE(6,1007) ALONGT,PEXIT,DPTOT,TNSH(IX),TSH(IX),QTOT
      WRITE(6,1008)
      WRITE(6,1009)
      WRITE(6,1010)
      WRITE(6,1011)
      WRITE(6,1012) WNTOT,WNNET,WH,DHNAK,DHHG,QKW,QHL,DTPP,DTTERM,DTSHEX
      WRITE(6,1013)
      WRITE(6,1014) RCNF,D1
      WRITE(6,1015) RCNT,TTA
      WRITE(6,1016) RCST,TNAK
      WRITE(6,1017) RCHT,TSS
      WRITE(6,1018) RR,D2
      WRITE(6,1019) PMPP,AKNT
      WRITE(6,1020) AN2,AKST
      WRITE(6,1021) DMPP,AKHT
      WRITE(6,1022) HMPP,DEMPP
      WRITE(6,1023) HHMPP,ACMPP
      WRITE(6,1024) PHELIX,DEH
      WRITE(6,1025) THICK,AH
      WRITE(6,1026) DBAR,AN1
C
C
      IF(ITABLE.EQ.0) GO TO 9000
      IPAGE=IPAGE+1
      WRITE(6,1000) IPAGE,DATE,COMENT
      WRITE(6,1027)
      CALL SETUP(15,'PHBONO.','TNAK.','THG.','P.','LENGTH.','QFLUX.',
     1 'U.','DTNHG.', 'H.','DTFILM.','RE.','PR.','NU.','PE.','ZETA.')
      CALL TABLE(LX,K,TNPH,THPH,PPH,ALPH,QFPH,UPH,DTPHB,HPH,DTPHF,REPH,
     1 PRPH,ANUPH,PEPH,FL)
      IF(JTABLE.EQ.0) GO TO 8000
C
      CALL SETUP(9,'PHLENGTH.','T4.','T3.','T2.','T1.','DTTA.',
     1 'DTSTAG.','DTSS.','DTTOTAL.')
      CALL TABLE(LX,ALPH,T4PH,T3PH,T2PH,T1PH,DTTAPH,DTSTPH,DTSSPH,
     1 DTTOPH)
C
C
 8000 IF(IGEOM.EQ.3) GO TO 8001
      IPAGE=IPAGE+1
      WRITE(6,1000) IPAGE,DATE,COMENT
      WRITE(6,1028)
      CALL SETUP(18,'XP.','TNAK.','THG.','P.','LENGTH.','QFLUX.',
     1 'U.','DTNHG.','H.','DTFILM.','NU.','XXX.','YYY.','PHI.','ZETA.',
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     2 'RO.','LIQ FILM.','RE.')
      CALL TABLE(IMAX,XP,TNXP,TXP,PXP,ALXP,QFXP,UXP,DTXPB,HXP,DTXPF,
     1 ANUXP,XXX,YYY,PHIXP,FXPGP,ROMPP,FILMXP,REXPGP)
C
      IF(JTABLE.EQ.0) GO TO 8001
      CALL SETUP(9,'XPLENGTH.','T4.','T3.','T2.','T1.','DTTA.',
     1 'DTSTAG.',':TSS.','DTTOTAL.')
      CALL TABLE(IMAX,ALXP,T4XP,T3XP,T2XP,T1XP,DTTAXP,DTSTXP,DTSSXP,
     1 DTTOXP)
C
C
 8001 IPAGE=IPAGE+1
      WRITE(6,1000) IPAGE,DATE,COMENT
      WRITE(6,1029)
      CALL SETUP(20,'XWET.','THAK.','THG.','P.','LENGTH.','QFLUX.',
     1 'U.','DTNHG.','H.','DTFILM.','NU.','XX.','YY.','PHI.','ZETA.',
     2 'ZETALIN.','ZETATAN.','RO.','LIQ FILM.','RE VAP.')
      CALL TABLE(NMAX,X,TNX,TX ,PX,ALX,QFX,UX,DTXB,HX,DTXF,ANUX,XX,YY,
     1 RATIO,FXGP,FGLIN,FGXTAN,ROX,FILMX,REX)
C
      IF(JTABLE.EQ.0) GO TO 8002
      CALL SETUP(9,'XLENGTH.','T4.','T3.','T2.','T1.', 'DTTA.',
     1'DTSTAG.','DTSS.','DTTOTAL.')
      CALL TABLE(NMAX,ALX,T4X,T3X,T2X,T1X,DTTAX,DTSTX,DTSSX,DTTOX)
C
C
 8002 IPAGE=IPAGE+1
      WRITE(6,1000) IPAGE,DATE,COMENT
      WRITE(6,1030)
      CALL SETUP(18,'BOUNDARY.','TNAK.','THG.','P.','LENGTH.','QFLUX.',
     1 'U.','DTNHG.','H.','DTFILM.','RESH.','ANULIN.','HLIN.','ANUFOR.',
     2 'HFOR.','FVSH.','FVSHLN.','FVTAN.')
      CALL TABLE(IX,KSH,TNSH,TSH,PSH,ALSH,QFSH,USH,DTMSH,HSH,DTSHF,
     1RESH,ANULIN,HLIN,ANUFOR,HFOR,FVSH,FVSHLN,FVTAN)
C
      IF(JTABLE.EQ.0) GO TO 9000
      CALL SETUP(9,'SHLENGTH.','T4.','T3.','T2.','T1.','DTTA.',
     1 'DTSTAG.','DTSS.','DTTOTAL.')
      CALL TABLE(IX,ALSH,T4SH,T3SH,T2SH,T1SH,DTTASH,DTSTSH,DTSSSH,
     1DTTOSH)
 9000 IPAGE=IPAGE+1
      WRITE(6,1000) IPAGE,DATE,COMENT
      WRITE(6,1031)
      WRITE(6,1032)
     1     WH,TNBOO,TSS,PHBOO,QHL,HNF,THBI,D1,AKNT,THBOO,TTA,AKST,TNBI,
     2     TNAK,AKHT
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      WRITE(6,1033)
     1     DPHITR,PTRLOO,AN2,DPLOTR,PMPP,XL,CONV,DMPP,DX,CNT,HMPP,
     2     DELMPP,PTRHII,AN1,FXINT
      WRITE(6,1034)
     1     CONXP,FINTX,DELTOT,DBAR,CONX,ITABLE,PHELIX,DROPNO,JTABLE,
     2     THICK,XO,IGEOM,XWET,XI,PITCH1
      WRITE(6,1035)
     1     DBAR1,THICK1,C1,C2,WNTOTT
C
C     FORMAT STATEMENTS
C
 1000 FORMAT(1H1,/////
     *            19X,73HSNAP-8 BODEPE COMPUTER PROGRAM  -  BOILER DESIGN
     1 AND PERFORMANCE ANALYSIS,3X,7HOUTPUT ,I3/
     2 1H0,5HDATE ,2A4,6X,18A4)
 1001 FORMAT(1H0,47X,13HS U M M A R Y/
     1 1H0,21X,6HLENGTH,5X,5HINLET,3X,8HPRESSURE,2X,9HMEAN HEAT,1X,
     2      8HNAK TEMP,2X,7HHG TEMP,5X,4HMASS,5X,4HHEAT,6X,1HX/
     3      31X,8HPRESSURE,4X,4HDROP,6X,4HFLUX,4X,7HSECT.IN,3X,7HSECT.IN,
     4      3X,8HVELOCITY,3X,5HINPUT,4X,4HEXIT/
     5      24X,2HFT,7X,4HPSIA,7X,3HPSI, 4X,8HB/H-SQFT,3X,5HDEG.F,5X,
     6      5HDEG.F,4X,9HLB/S-SQFT,2X,4HB/HR)
 1002 FORMAT(1H0,14HMPPPH  SECTION,F12.1,F11.1,F9.1,F11.0,F10.0,F10.0,
     1      F10.1,F11.0,2X,4H0.0 )
 1003 FORMAT(1H ,14HMPPXP  SECTION,F12.1,F11.1,F9.1,F11.0,2F10.0,
     1      F10.1,F11.0,1X,F5.2)
 1004 FORMAT(1H ,14HSFHXX  SECTION,F12.1,F11.1,F9.1,F11.0,2F10.0,
     1      F10.1,F11.0,2X,4H1.00)
 1005 FORMAT(1H ,14HSFHXSH SECTION,F12.1,F11.1,F9.1,F11.0,2F10.0,
     1      F10.1,F11.0)
 1006 FORMAT(1H ,15HEXCESSH SECTION,F11.1,F11.1,F9.1,F21.0,F10.0,F10.1)
 1007 FORMAT(1H ,14HTOTAL  BOILER ,F12.1,3X,1H*,F7.1,F9.1,13X,1H*,F7.0,
     1       2X,1H*,F7.0,F21.0)
 1008 FORMAT(1H ,16X,19H* - EXIT PARAMETERS)
 1009 FORMAT(1H0,6X,8HNAK FLOW,6X,7HMERCURY,4X,15HENTHALPY CHANGE,4X,
     1       7HTHERMAL,3X,9HHEAT LOSS,2X,5HPINCH,4X,8HTERMINAL,3X,
     2       5HVAPOR)
 1010 FORMAT(1H ,2X,5HTOTAL,6X,3HNET,6X,4HFLOW,6X,3HNAK,8X,2HHG,5X,
     1       5HPOWER,5X,8HEXTERNAL,2X,18HPOINT DT NAK-HG DT,2X,
     2       9HSUPERHEAT)
 1011 FORMAT(1H ,2X,5HLB/HR,5X,5HLB/HR,4X,5HLB/HR,4X,6HBTU/LB,5X,
     1       6HBTU/LB,5X,2HKW,9X,2HKW,5X,5HDEG.F,5X,5HDEG.F,5X,5HDEG.F)
 1012 FORMAT(1H0,F8.0,F10.0,F9.0,F9.0,F9.0,F10.0,F11.0,F10.1,F11.1,F9.0)
 1013 FORMAT(1H0,10X,72HTHERMAL PASS RESISTANCES,MATERIAL CONDUCTIVITIES
     1 AND HG PASSAGE GEOMETRY)
 1014 FORMAT(1H0,6HRCNF =,F9.6,2X,17HHR-SQFT-DEG.F/BTU,5X,8HNAK FILM,
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    1 13X,4HD1 =,F6.3,5H INCH,5X,10HHG TUBE ID)
1015 FORMAT(1H ,6HRCNT =,F9.6,2X,17HHR-SQFT-DEG.F/BTU,5X,7HSS TUBE,
    1 13X,5HTTA =,F6.3,5H INCH,5X,17HTA WALL THICKNESS)
1016 FORMAT(1H ,6HRCST =,F9.6,2X,17HHR-SQFT-DEG.F/BTU,5X,12HSTAGNANT NA
    1K,8X,5HTST =,F6.3,5H INCH,5X,25HSTAGN.NAK THICKNESS(MEAN))
1017 FORMAT(1H ,6HRCHT =,F9.6,2X,17HHR-SQFT-DEG.F/BTU,5X,7HTA TUBE,
    1 13X,5HTSS =,F6.3,5H INCH,5X,17HSS WALL THICKNESS)
1018 FORMAT(1H ,6H  RR =,F9.6,2X,17HHR-SQFT-DEG.F/BTU,5X,14HTOTAL OF AB
    1OVE,7X,4HD2 =,F6.3,5H INCH,5X,11HHG TUBE OD.)
1019 FORMAT(1H0,2X,6HPMPP =,F6.3,2X,4HINCH,5X,9HMPP PITCH,25X,
    1 6HKSS  =,F5.2,2X,15HBTU/HR-FT-DEG.F,2X,15HCONDUCTIVITY,SS)
1020 FORMAT(1H ,4X,4HN2 =,F4.0,13X,          25HNUMBER OF PASSAGES IN MP
    1P,9X,6HKNAK =, F5.2,2X,33HBTU/HR-FT-DEG.F  CONDUCTIVITY,NAK)
1021 FORMAT(1H ,2X,6HDMPP =,F6.3,2X,4HINCH,5X,13HPASSAGE WIDTH,21X,
    1 6HKTA  =,F5.2,2X,15HBTU/HR-FT-DEG.F,2X,15HCONDUCTIVITY,TA)
1022 FORMAT(1H ,2X,6HHMPP =,F6.3,2X,4HINCH,5X,17HPASSAGE HEIGTH(1),17X,
    1 6HDEMPP=,F7.4,4X,4HINCH, 9X,11HDIA.EQ.,MPP)
1023 FORMAT(1H ,8H HHMPP =,F6.3,2X,4HINCH,5X,17HPASSAGE HEIGTH(2),17X,
    1 6HACMPP=,F7.4,4X,6HSQINCH,7X,13HCROSSECT.AREA)
1024 FORMAT(1H ,8H PHELIX=,F6.3,2X,4HINCH,5X,10HSFHX PITCH,24X,
    1 6HDEH  =,F7.4,4X,4HINCH, 9X,12HDIA.EQ.,SFHX)
1025 FORMAT(1H ,8H THICK =,F6.3,2X,4HINCH,5X,20HSFHX STRIP THICKNESS,
    1 14X,6HAH   =,F7.4,4X,6HSQINCH,7X,13HCROSSECT.AREA)
1026 FORMAT(1H ,8H DBAR  =,F7.4,5H INCH,5X,13HCENTER BAR OD,21X,
    1 6HN1   =,F3.0,21X,15HNUMBER OF TUBES)
1027 FORMAT(1H0,95X,10HPH SECTION)
1028 FORMAT(1H0,95X,10HXP SECTION)
1029 FORMAT(1H0,92X,13HSFHXX SECTION)
1030 FORMAT(1H0,91X,14HSFHXSH SECTION)
1031 FORMAT(1H0,46X,10HINPUT DATA)
1032 FORMAT(
    1 1H0,18X,8HWH     =,F13.3,8X,8HTNBO   =,F13.3,8X,8HTSS    =,F13.3/
    2 1H ,18X,8HPHBO   =,F13.3,8X,8HQHL    =,F13.3,8X,8HHNF    =,F13.3/
    3 1H ,18X,8HTHBI   =,F13.3,8X,8HD1     =,F13.3,8X,8HAKNT   =,F13.3/
    4 1H ,18X,8HTHBO   =,F13.3,8X,8HTTA    =,F13.3,8X,8HAKST   =,F13.3/
    5 1H ,18X,8HTNBI   =,F13.3,8X,8HTNAK   =,F13.3,8X,8HAKHT   =,F13.3)
1033 FORMAT(
    1 1H0,18X,8HDPHITR =,F13.3,8X,8HPTRLO  =,F13.3,8X,8HAN2    =,F13.3/
    2 1H ,18X,8HDPLOTR =,F13.3,8X,8HPMPP   =,F13.3,8X,8HXL     =,F13.3/
    3 1H ,18X,8HCONV   =,F13.3,8X,8HDMPP   =,F13.3,8X,8HDX     =,F13.3/
    4 1H ,18X,8HCNT    =,F13.3,8X,8HHMPP   =,F13.3,8X,8HDELMPP =,F13.3/
    5 1H ,18X,8HPTRHI  =,F13.3,8X,8HAN1    =,F13.3,8X,8HFXINT  =,F13.3)
1034 FORMAT(
    1 1H0,18X,8HCONXP  =,F13.3,8X,8HFINTX  =,F13.3,8X,8HDELTOT =,F13.3/
    2 1H ,18X,8HDBAR   =,F13.3,8X,8HCONX   =,F13.3,8X,8HITABLE =,I13/
    3 1H ,18X,8HPHELIX =,F13.3,8X,8HDROPNO =,F13.3,8X,8HJTABLE =,I13/
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    4 1H ,18X,8HTHICK   =,F13.3,8X,8HXO      =,F13.3,8X,8HIGEOM  =,I13/
    5 1H ,18X,8HXWET    =,F13.3,8X,8HXI      =,F13.3,8X,8HPITCH1 =,F13.3)
 1035 FORMAT(
    1 1H0,18X,8HDRAR1   =,F13.3                                        /
    2 1H ,18X,8HTHICK1  =,F13.3                                        /
    3 1H ,18X,8HC1      =,F13.3                                        /
    4 1H ,18X,8HC2      =,F13.3                                        /
    5 1H ,18X,8HWNTOTT  =,F13.3                                        )
      RETURN
      END
      FUNCTION RPROOT(PPMOR)
      REAL LHS
      COMMON/ROPRIM/BETA,RORO
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      PPMOR=ABS(PPMOR)
      LHS=128.*YYY(J)*((PPMOR   **2-RORO**2)*BETA/2.+3.14159/8.*BETA**2*
     XRORO**2)**3/(TNIXF*BETA*XXX(J)*(BETA*PPMOR   +2.*(PPMOR   -RORO
     X)+.5*3.14159*RORO*BETA))
      RHS=(1.-PPMOR   **2)**2
      RPROOT=(LHS-RHS)/LHS
      RETURN
      END
      FUNCTION XPROOT(PPMOR)
      REAL LHS
      COMMON/ROXP/AMUXPF,AMUXPV
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      PPMOR=ABS(PPMOR)
      PIFNC=4.*3.14159/TNIXF
      RATMU=AMUXPF/AMUXPV
      RATRHO=(PPMOR**2-1.0)/PPMOR**3
      PART=.5*XXX(J)*RATMU*RATRHO-PIFNC*XXX(J)*YYY(J)*RATMU**2
      CHECK=SQRT(-1.*PIFNC*XXX(J)**2*YYY(J)*RATMU**3*RATRHO+PIFNC**2*
     1 XXX(J)**2*YYY(J)**2*RATMU**4)
      LHS=1./PPMOR
      RHS=-CHECK-PART
      XPROOT=(LHS-RHS)/LHS
      RETURN
      END
      FUNCTION ROROOT(XOR)
      REAL LHS
      COMMON/RHO/AMUXF,AMUXV,NK
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      XOR=ABS(XOR)
```

```
      PIFNC=4.*3.14159/XTNIF
      RATMU=AMUXF/AMUXV
      RATRHO=(XOR     **2-1.)/XOR     **3
      PART=.5*XX(NN)*RATMU*RATRHO-PIFNC*XX(NN)*YY(NN)*RATMU**2
      CHECK=SQRT(-1.* PIFNC*XX(NN)**2*YY(NN)*RATMU**3*RATRHO+PIFNC**2*
     XXX(NN)**2*YY(NN)**2*RATMU**4)
      LHS=1./XOR
      RHS=-CHECK-PART
      ROROOT=(LHS-RHS)/LHS
      RETURN
      END
      FUNCTION TFROOT(FXTD)
C
      REAL LHS
      COMMON/DLTF/CCC
      COMMON/RR/ RR
      COMMON/XY/ XXX(51),YYY(51),J,TNIXF,XX(51),YY(51),
     1  DTXB(51),NN,XTNIF
      FXTD=ABS(FXTD)
      LHS=FXTD
      RHS=RR*CCC*FXTD     **0.6-DTXB(NN)
      TFROOT=(LHS+RHS)/LHS
      RETURN
      END
      FUNCTION SHROOT(DTSHF)
      COMMON/SHSH/GCON1,GCON2,GSHB
      REAL LHS
      DTSHF=ABS(DTSHF)
      LHS=DTSHF**1.3333
      RHS=GCON2*DTSHF-GSHB/GCON1
      SHROOT=(LHS+RHS)/LHS
      RETURN
      END
      SUBROUTINE ROOT(/G/,XLO,XHI,CONV,NPASS,ISTEP,XAVE,IERR)
C
C     GENERAL ROUTINE TO FIND A ROOT OF A SINGLE VALUE FUNCTION G(X)
C               IS IN CALLING PROGRAM WHICH EXTRNAL CARD
C
C
C     CONV - LIMITING ABSOLUTE VALUE OF G
C     IERR - NOT EQUAL ZERO INDICATES NO CONVERGENCE OR ERRORS
C     NPASS- NO OF INTERVAL HALFINGS
C     ISTEP- LOCATION IN CALLING PROGRAM
C
      DIMENSION GX(7),X(7)
      IERR=0
```

```
      GXHI=G(XHI)
      SIGNG=SIGN(1.0,GXHI)
      GXLO=G(XLO)
      SIGNGL=SIGN(1.0,GXLO)
      IF(SIGNG.NE.SIGNGL) GO TO 10
      DELX=(XHI-XLO)/4.0
      X(1)=XLO-DELX
      DO 50 I=2,7
      X(I)=X(I-1)+DELX
   50 CONTINUE
      DO 55 I=1,7
      GX(I)=G(X(I))
   55  CONTINUE
      WRITE(6,1000) ISTEP,XLO,XHI,(X(I),GX(I),I=1,7)
 1000 FORMAT(1H0,10X,53HIN CALLING ROOT BOTH G(XHI) AND G(XLO) HAVE SAME
     1 SIGN// 25X,7HISTEP =,I10,5X,5HXLO =,1PE12.5,5X,5HXHI =,E12.5//
     2  1H0,40X,15X,4HG(X)/(1H0,35X,1PE12.4,E21.4))
      IERR=1
      XAVE=0.0
      RETURN
   10 DO 20 I=1,NPASS
      XAVE=0.5*(XHI+XLO)
      GAVE=G(XAVE)
      IF(ABS(GAVE).LE.CONV) RETURN
      IF(SIGNG.EQ.SIGN(1.0,GAVE)) GO TO 21
      XLO=XAVE
      GO TO 20
   21 XHI=XAVE
   20 CONTINUE
      IERR=1
      RETURN
      END
      FUNCTION PTNA(X)
C     VAPOR PRESSURE AS A FUNCTION OF TEMP.
      DIMENSION TEMP(11),PNAK(11)
      DATA TEMP/ 820.000, 850.066, 899.185, 950.763, 1000.02, 1050.17,
     1           1149.37, 1252.02, 1349.87, 1400.00, 0.0/
      DATA PNAK/ .119000, .170335, .287456, .468178, .730625, 1.12203,
     2           2.39042, 4.80700, 8.41623, 11.0800, 0.0/
        ENTRY  PNAT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      PTNA=PNAK(1)
  110 CALL PERR(4HPNAT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(10)) GO TO 130
```

```
      PTNA=PNAK(10)
      GO TO 110
  130 CALL INT4(TEMP,PNAK,T,V)
      PTNA=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR PRESSURE
      ENTRY TNAP(P,ISTEP,IERR)
      IF(P.GE.PNAK(1)) GO TO 150
      PTNA=TEMP(1)
  140 CALL PERR(4HTNAP,ISTEP,P)
      IERR=1
      RETURN
  150 IF(P.LE.PNAK(10)) GO TO 160
      PTNA=TEMP(10)
      GO TO 140
  160 CALL INT4(PNAK,TEMP,P,TT)
      PTNA=TT
      IERR=0
      RETURN
      END
      FUNCTION CPTNA(X)
C     SPEC. HEAT. AS A FUNCTION OF TEMP.
      DIMENSION TEMP(19),CPNAK(19),TEMPI(13),CPNAKI(13)
      DATA TEMP/ 68.0000, 74.9754, 150.151, 250.010, 349.988, 450.027,
     1           549.899, 649.905, 749.935, 849.306, 900.001, 960.000,
     2           996.568, 1049.84, 1149.94, 1250.41, 1350.62, 1400.00,
     3           0.0/
      DATA CPNAK/.234200, .233541, .227855, .222413, .218253, .215025,
     1           .212656, .210854, .209688, .208990, .208800, .208779,
     2           .208889, .209048, .209629, .210521, .211586, .212200,
     3           0.0/
      DATA TEMPI/  960.000, 900.001, 849.306, 749.935, 649.905, 549.899,
     1             450.027, 349.988, 250.010, 150.151, 79.9754, 68.0000,
     2             0.0/
      DATA CPNAKI/ .208779, .208800, .208990, .209688, .210854, .212656,
     1             .215025, .218253, .222413, .227855, .233541, .234200,
     2             0.0/
        ENTRY  CPNAT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      CPTNA=CPNAK(1)
  110 CALL PERR(5HCPNAT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(18)) GO TO 130
      CPTNA=CPNAK(18)
```

```
      GO TO 110
  130 CALL INT4(TEMP,CPNAK,T,V)
      CPTNA=V
      IERR=0
      RETURN
C     TEMP. AS A FUNCTION OF SPEC. HEAT
C      RANGE  68.0 TO 910.0 DEG
       ENTRY TNACP1(CP,ISTEP,IERR)
      IF(CP.GE.CPNAKI(1)) GO TO 150
      CPTNA=TEMPI(1)
  140 CALL PERR(6HTNACP1,ISTEP,CP)
      IERR=1
      RETURN
  150 IF(CP.LE.CPNAKI(12)) GO TO 160
      CPTNA=TEMPI(12)
      GO TO 140
  160 CALL INT4(CPNAKI,TEMPI,CP,TT)
      CPTNA=TT
      IERR=0
      RETURN
C     TEMP. AS A FUNCTION OF SPEC. HEAT
C     RANGE   960.0 TO 1400.0 DEG.
      ENTRY TNACP2(CP2,ISTEP,IERR)
      IF(CP2.GE.CPNAK(12)) GO TO 180
      CPTNA=TEMP(12)
  170 CALL PERR(6HTNACP2,ISTEP,CP2)
      IERR=1
      RETURN
  180 IF(CP2.LE.CPNAK(18)) GO TO 190
      CPTNA=TEMP(18)
      GO TO 170
  190 CALL INT4(CPNAK(12),TEMP(12),CP2,TT)
      CPTNA=TT
      IERR=0
      RETURN
      END
      FUNCTION CTNA(X)
C     THERM. COND. AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16),CNAK(16),TEMPI(9),CNAKI(9)
      DATA TEMP/ 300.000, 350.006, 447.630, 551.443, 649.942, 749.078,
     1           799.998, 849.999, 900.000, 950.381, 1050.41, 1150.07,
     2           1249.97, 1350.19, 1400.00, 0.0/
      DATA CNAK/ 13.7600, 14.0632, 14.5478, 14.8716, 15.0494, 15.1472,
     1           15.1680, 15.1720, 15.1600, 15.1338, 15.0436, 14.9324,
     2           14.8070, 14.6668, 14.5900, 0.0/
      DATA TEMPI/ 1400.00, 1350.19, 1249.97, 1150.07, 1050.41, 950.381,
```

```
     1            900.000, 849.999, 0.0/
      DATA CNAKI/ 14.5900, 14.6668, 14.8070, 14.9324, 15.0436, 15.1338,
     1             15.1600, 15.1720, 0.0/
        ENTRY  CNAT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      CTNA=CNAK(1)
  110 CALL PERR(4HCNAT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      CTNA=CNAK(15)
      GO TO 110
  130 CALL INT4(TEMP,CNAK,T,V)
      CTNA=V
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID THERM. COND.
C      RANGE 68.0 DEG TO 800.0 DEG
      ENTRY TNAC1(C,ISTEP,TERR)
      IF(C.GE.CNAK(1)) GO TO 150
      CTNA=TEMP(1)
  140 CALL PERR(5HTNAC1,ISTEP,C)
      IERR=1
      RETURN
  150 IF(C.LE.CNAK(8))  GO TO 160
      CTNA=TEMP(8)
      GO TO 140
  160 CALL INT4(CNAK,TEMP,C,TT)
      CTNA=TT
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID THERM. COND.
C     RANGE 800.0 TO 1400.0 DEGREES
      ENTRY TNAC2(C2,ISTEP,IERR)
      IF(C2.GE.CNAKI(1)) GO TO 180
      CTNA=TEMPI(1)
  170 CALL PERR(5HTNAC2,ISTEP,C2)
      IERR=1
      RETURN
  180 IF(C2.LE.CNAKI(8)) GO TO 190
      CTNA=TEMPI(8)
      GO TO 170
  190 CALL INT4(CNAKI,TEMPI,C2,TT)
      CTNA=TT
      IERR=0
      RETURN
      END
```

```
      FUNCTION VTNA(X)
C     VISCOSITY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16),VNAK(16),TEMPI(16),VNAKI(16)
      DATA TEMP/ 68.0000, 99.9124, 199.171, 299.962, 400.256, 499.687,
     1           599.778, 700.587, 800.118, 900.285, 1000.05, 1099.98,
     2           1200.03, 1300.00, 1400.00, 0.0/
      DATA VNAK/ 1.56000, 1.46213, 1.17292, .939505, .779196, .663212,
     1           .578366, .520178, .478521, .445545, .417332, .390436,
     2           .364822, .340010, .315000, 0.0/
      DATA TEMPI/ 1400.00, 1300.00, 1200.03, 1099.98, 1000.05, 900.285,
     1            800.118, 700.587, 599.778, 499.687, 400.256, 299.962,
     2            199.171, 99.9124, 68.0000, 0.0/
      DATA VNAKI/ .315000, .340010, .364822, .390436, .417332, .445545,
     1            .478521, .520178, .578366, .663212, .779196, .939505,
     2            1.17292, 1.46213, 1.56000, 0.0/
        ENTRY  VNAT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      VTNA=VNAK(1)
  110 CALL PERR(4HVNAT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      VTNA=VNAK(15)
      GO TO 110
  130 CALL INT4(TEMP,VNAK,T,VV)
      VTNA=VV
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID VISCOSITY
      ENTRY TNAV(V,ISTEP,IERR)
      IF(V.GE.VNAKI(1)) GO TO 150
      VTNA=TEMPI(1)
  140 CALL PERR(4HTNAV,ISTEP,V)
      IERR=1
      RETURN
  150 IF(V.LE.VNAKI(15)) GO TO 160
      VTNA=TEMPI(15)
      GO TO 140
  160 CALL INT4(VNAKI,TEMPI,V,TT)
      VTNA=TT
      IERR=0
      RETURN
      END
      FUNCTION RTNA(X)
C     DENSITY AS A FUNCTION OF TEMP
      DIMENSION TEMP(16),RNAK(16),TEMPI(16),RNAKI(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
```

```
     1     700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2       0.0/
      DATA RNAK/ 54.10, 53.82, 53.00, 52.17, 51.33, 50.50, 49.66, 48.82,
     1     48.00, 47.15, 46.30, 45.47, 44.65, 43.80, 42.96, 0.0/
      DATA TEMPI/ 1400.0, 1300.0, 1200.0, 1100.0, 1000.0, 900.0, 800.0,
     1 700.0, 600.0, 500.0, 400.0, 300.0, 200.0, 100.0, 68.0,0.0/
      DATA RNAKI/ 42.96, 43.80, 44.65, 45.47, 46.30, 47.15, 48.00,
     1 48.82, 49.66, 50.50, 51.33, 52.17, 53.00, 53.82, 54.10, 0.0/
        ENTRY  RNAT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      RTNA=RNAK(1)
  110 CALL PERR(4HRNAT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      RTNA=RNAK(15)
      GO TO 110
  130 CALL INT4(TEMP,RNAK,T,V)
      RTNA=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID DENSITY
      ENTRY TNAR(R,ISTEP,IERR)
      IF(R.GE.RNAKI(1)) GO TO 150
      RTNA=TEMPI(1)
  140 CALL PERR(4HTNAR,ISTEP,R)
      IERR=1
      RETURN
  150 IF(R.LE.RNAKI(15)) GO TO 160
      RTNA=TEMPI(15)
      GO TO 140
  160 CALL INT4(RNAKI,TEMPI,R,TT)
      RTNA=TT
      IERR=0
      RETURN
      END
      FUNCTION STHGG(X)
C     VAPOR  ENTROPY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16),SVHG(16),TEMPI(16),SVHGI(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1     700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2       0.0/
      DATA  SVHG/  .2740, .2475, .2080, .1851, .1683, .1553, .1451,
     1       .1369, .1301, .1245, .1198, .1158, .1123, .1093, .1067, 0.0/
      DATA TEMPI/ 1400.0, 1300.0, 1200.0, 1100.0, 1000.0, 900.0, 800.0,
     1 700.0, 600.0, 500.0, 400.0, 300.0, 200.0, 100.0, 68.0,0.0/
```

```
      DATA SVHGI/ .1067, .1093, .1123, .1158, .1198, .1245, .1301,
     1 .1369, .1451, .1553, .1683, .1851, .2080, .2475, .2740, 0.0/
        ENTRY  SHGGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      STHGG=SVHG(1)
  110 CALL PERR(6HSHGGT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      STHGG=SVHG(15)
      GO TO 110
  130 CALL INT4(TEMP,SVHG,T,V)
      STHGG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR ENTROPY
      ENTRY THGGS(SV,ISTEP,IERR)
      IF(SV.GE.SVHGI(1)) GO TO 150
      STHGG=TEMPI(1)
  140 CALL PERR(5HTHGGS,ISTEP,SV)
      IERR=1
      RETURN
  150 IF(SV.LE.SVHGI(15)) GO TO 160
      STHGG=TEMPI(15)
      GO TO 140
  160 CALL INT4(SVHGI,TEMPI,SV,TT)
      STHGG=TT
      IERR=0
      RETURN
      END
      FUNCTION STHGL(X)
C     LIQUID ENTROPY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), SLHG(16)
      DATA TEMP/ 68.0,153.731,249.700,350.222,450.020,550.030,650.034,
     1 749.932,850.092,949.950,1049.98,1150.05,1249.91,1350.20,1400.0,
     2  0.0/
      DATA SLHG/ 1.80000E-03,7.37344E-03,1.193735E-02,1.64937E-02,
     1 2.02062E-02,2.34937E-02,2.64312E-02,2.91312E-02,3.15750E-02,
     2 3.38187E-02,3.59250E-02,3.78187E-02,3.95687E-02, 4.11750E-02,
     3 4.19000E-02, 0.0/
        ENTRY  SHGLT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      STHGL=SLHG(1)
  110 CALL PERR(6HSHGLT ,ISTEP,T)
      IERR=1
      RETURN
```

```
  120 IF(T.LE.TEMP(15)) GO TO 130
      STHGL=SLHG(15)
      GO TO 110
  130 CALL INT4(TEMP,SLHG,T,V)
      STHGL=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID ENTROPY
      ENTRY THGLS(SL,ISTEP,IERR)
      IF(SL.GE.SLHG(1)) GO TO 150
      STHGL=TEMP(1)
  140 CALL PERR(5HTHGLS,ISTEP,SL)
      IERR=1
      RETURN
  150 IF(SL .LE.SLHG(15)) GO TO 160
      STHGL=TEMP(15)
      GO TO 140
  160 CALL INT4(SLHG,TEMP,SL,TT)
      STHGL=TT
      IERR=0
      RETURN
      END
      FUNCTION HTNA(X)
C     ENTALPY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), HNAK(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA HNAK/  10.0,  17.0,  38.5,  61.0,  82.0, 103.0, 125.0, 146.0,
     1    167.0, 188.0, 209.0, 229.0, 251.0, 272.0, 292.0,  0.0/
        ENTRY  HNAT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      HTNA=HNAK(1)
  110 CALL PERR(4HHNAT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      HTNA=HNAK(15)
      GO TO 110
  130 CALL INT4(TEMP,HNAK,T,V)
      HTNA=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID ENTHALPY
      ENTRY TNAH(H,ISTEP,IERR)
      IF(H.GE.HNAK(1)) GO TO 150
```

```
      HTNA=TEMP(1)
  140 CALL PERR(4HTNAH,ISTEP,H)
      IERR=1
      RETURN
  150 IF(H.LE.HNAK(15)) GO TO 160
      HTNA=TEMP(15)
      GO TO 140
  160 CALL INT4(HNAK,TEMP,H,TT)
      HTNA=TT
      IERR=0
      RETURN
      END
      FUNCTION PTHG(X)
C      VAPOR PRESSURE AS A FUNCTION OF TEMP.
      DIMENSION TEMP(21), VPHG(21)
      DATA TEMP/ 68.0,87.50,100.0,150.0,200.0,250.0,300.0,350.0,400.0,
     1 450.0,550.0,650.0,750.0,850.0,950.0,1050.0,1150.0,1250.0,1350.0,
     2 1400.0, 0.0/
      DATA VPHG/ 1.85E-05,5.91E-05,1.11E-04,7.25E-04,3.64E-03,1.52E-02,
     1 5.23E-02,1.29881E-01,3.86E-01,8.46919E-01,3.57644,11.4131,
     2 29.7751,66.7125,132.752,240.882,399.444,622.627,922.125,1100.00,
     3 0.0/
        ENTRY  PHGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      PTHG=VPHG(1)
  110 CALL PERR(6HPGHT  ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(20)) GO TO 130
      PTHG=VPHG(20)
      GO TO 110
  130 CALL INT4(TEMP,VPHG,T,V)
      PTHG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR PRESSURE
      ENTRY THGP(VP,ISTEP,IERR)
      IF(VP .GE.VPHG(1)) GO TO 150
      PTHG=TEMP(1)
  140 CALL PERR(4HTHGP,ISTEP,VP)
      IERR=1
      RETURN
  150 IF(VP .LE.VPHG(20)) GO TO 160
      PTHG=TEMP(20)
      GO TO 140
  160 CALL INT4(VPHG,TEMP,VP,TT)
```

```
      PTHG=TT
      IERR=0
      RETURN
      END
      FUNCTION CTHGG(X)
C     VAPOR THERM. COND. AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), CVHG(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA CVHG/  .00110, .00155, .00217, .00296, .00370, .00442,
     1    .00506, .00566, .00621, .00693, .00777, .00875, .00985,
     2    .01105, .01238,  0.0/
        ENTRY  CHGGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      CTHGG=CVHG(1)
  110 CALL PERR(6HCHGGT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      CTHGG=CVHG(15)
      GO TO 110
  130 CALL INT4(TEMP,CVHG,T,V)
      CTHGG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR THERMAL COND.
      ENTRY THGGC(CV,ISTEP,IERR)
      IF(CV .GE.CVHG(1)) GO TO 150
      CTHGG=TEMP(1)
  140 CALL PERR(5HTHGGC,ISTEP,CV)
      IERR=1
      RETURN
  150 IF(CV .LE.CVHG(15)) GO TO 160
      CTHGG=TEMP(15)
      GO TO 140
  160 CALL INT4(CVHG,TEMP,CV,TT)
      CTHGG=TT
      IERR=0
      RETURN
      END
      FUNCTION CTHGL(X)
C     LIQUID THERM. COND. AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), CLHG(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
```

```
     2       0.0/
      DATA CLHG/  4.93, 5.06, 5.44, 5.81, 6.20, 6.58, 6.93, 7.18, 7.43,
     1            7.68, 7.93, 8.19, 8.44, 8.70, 8.94, 0.0/
        ENTRY  CHGLT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      CTHGL=CLHG(1)
  110 CALL PERR(6HCHGLT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      CTHGL=CLHG(15)
      GO TO 110
  130 CALL INT4(TEMP,CLHG,T,V)
      CTHGL=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID THERMAL COND.
      ENTRY THGLC(CL,ISTEP,IERR)
      IF(CL .GE.CLHG(1)) GO TO 150
      CTHGL=TEMP(1)
  140 CALL PERR(5HTHGLC,ISTEP,CL)
      IERR=1
      RETURN
  150 IF(CL .LE.CLHG(15)) GO TO 160
      CTHGL=TEMP(15)
      GO TO 140
  160 CALL INT4(CLHG,TEMP,CL,TT)
      CTHGL=TT
      IERR=0
      RETURN
      END
      FUNCTION CPTHGG(X)
C     VAPOR SPEC. HEAT AS A FUNCTION OF SATURATION TEMP.
      DIMENSION TEMP(16), CPVHG(16)
      DATA TEMP/ 200.0,250.0,300.0,350.0,450.0,550.0,650.0,750.0,850.0,
     1 950.0,1050.0,1150.0,1250.0,1350.0,1400.0, 0.0/
      DATA CPVHG/ 2.474E-02,2.47444E-02,2.47500E-02,2.47531E-02,
     1 2.47781E-02,2.48194E-02,2.48644E-02,2.49131E-02,2.49737E-02,
     2 2.50887E-02,2.52562E-02,2.54525E-02,2.56675E-02,2.59012E-02,
     3 2.60300E-02, 0.0/
        ENTRY  CPHGGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      CPTHGG=CPVHG(1)
  110 CALL PERR(6HCPHGGT,ISTEP,T)
      IERR=1
      RETURN
```

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  120 IF(T.LE.TEMP(15)) GO TO 130
      CPTHGG=CPVHG(15)
      GO TO 110
  130 CALL INT4(TEMP,CPVHG,T,V)
      CPTHGG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR SPECIFIC HEAT
      ENTRY THGGCP(CPV,ISTEP,IERR)
      IF(CPV.GE.CPVHG(1)) GO TO 150
      CPTHGG=TEMP(1)
  140 CALL PERR(6HTHGGCP,ISTEP,CPV)
      IERR=1
      RETURN
  150 IF(CPV.LE.CPVHG(15)) GO TO 160
      CPTHGG=TEMP(15)
      GO TO 140
  160 CALL INT4(CPVHG,TEMP,CPV,TT)
      CPTHGG=TT
      IERR=0
      RETURN
      END
      FUNCTION CPTHGL(X)
C     LIQUID SPECIFIC HEAT AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16),CPLHG(16),CPLHGI(8),TEMPI(8)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA CPLHG/   .03322, .03313, .03283, .03259, .03243, .03234,
     1  .03233, .03238, .03250, .03268, .03294, .03318, .03335,
     2    .03347, .03356, 0.0/
      DATA TEMPI/ 600.0, 500.0, 400.0, 300.0, 200.0, 100.0, 68.0, 0.0/
      DATA CPLHGI/  .03233, .03234, .03243, .03259, .03283, .03313,
     1   .03322, 0.0/
        ENTRY  CPHGLT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      CPTHGL=CPLHG(1)
  110 CALL PERR(6HCPHGLT,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      CPTHGL=CPLHG(15)
      GO TO 110
  130 CALL INT4(TEMP,CPLHG,T,V)
      CPTHGL=V
      IERR=0
```

```
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID SPECIFIC HEAT
C      RANGE 68.0 TO 600.0 DEGREES
      ENTRY THLCP1(CPL,ISTEP,IERR)
      IF(CPL.GE.CPLHGI(1)) GO TO 150
      CPTHGL=TEMPI(1)
  140 CALL PERR(6HTHLCP1,ISTEP,CPL)
      IERR=1
      RETURN
  150 IF(CPL.LE.CPLHGI(7)) GO TO 160
      CPTHGL=TEMPI(7)
      GO TO 140
  160 CALL INT4(CPLHGI,TEMPI,CPL,TT)
      CPTHGL=TT
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID SPECIFIC HEAT
C     RANGE 600.0 TO 1400.0 DEGREES
      ENTRY THLCP2(CPL1,ISTEP,IERR)
      IF(CPL1.GE.CPLHG(7)) GO TO 180
      CPTHGL=TEMP(7)
  170 CALL PERR(6HTHLCP2,ISTEP,CPL1)
      IERR=1
      RETURN
  180 IF(CPL1.LE.CPLHG(15)) GO TO 190
      CPTHGL=TEMP(15)
      GO TO 170
  190 CALL INT4(CPLHG(7),TEMP(7),CPL1,TT)
      CPTHGL=TT
      IERR=0
      RETURN
      END
      FUNCTION VTHGG(X)
C     VAPOR VISCOSITY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), VVHG(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA  VVHG/ .030, .035, .047, .060, .074, .089, .106, .124, .147,
     1            .176, .208, .240, .274, .309, .344,  0.0/
        ENTRY  VHGGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      VTHGG=VVHG(1)
  110 CALL PERR(6HVHGGT ,ISTEP,T)
      IERR=1
      RETURN
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  120 IF(T.LE.TEMP(15)) GO TO 130
      VTHGG=VVHG(15)
      GO TO 110
  130 CALL INT4(TEMP,VVHG,T,V)
      VTHGG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR VISCOSITY
      ENTRY THGGV(VV,ISTEP,IERR)
      IF(VV .GE.VVHG(1)) GO TO 150
      VTHGG=TEMP(1)
  140 CALL PERR(5HTHGGV,ISTEP,VV)
      IERR=1
      RETURN
  150 IF(VV .LE.VVHG(15)) GO TO 160
      VTHGG=TEMP(15)
      GO TO 140
  160 CALL INT4(VVHG,TEMP,VV,TT)
      VTHGG=TT
      IERR=0
      RETURN
      END
      FUNCTION VTHGL(X)
C     LIQUID VISCOSITY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), VLHG(16),TEMPI(16), VLHGI(16)
      DATA TEMP/ 68.0,150.334,251.290,348.845,451.174,548.931,651.091,
     1 749.979,849.507,950.343,1050.24,1149.65,1249.75,1351.06,1400.0,
     2  0.0/
      DATA VLHG/3.75,3.23492,2.86687,2.59187,2.37812,2.22062,2.09625,
     1 2.00375,1.91812,1.84812,1.79437,1.74437,1.69875,1.66375,1.65000,
     2 0.0/
      DATA TEMPI/ 1400.0, 1300.0, 1200.0, 1100.0, 1000.0, 900.0, 800.0,
     1 700.0, 600.0, 500.0, 400.0, 300.0, 200.0, 100.0, 68.0,0.0/
      DATA VLHGI/ 1.65, 1.68, 1.72, 1.77, 1.82, 1.88, 1.96, 2.05, 2.15,
     1 2.30, 2.47, 2.73, 3.03, 3.50, 3.75, 0.0/
        ENTRY  VHGLT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      VTHGL=VLHG(1)
  110 CALL PERR(6HVHGLT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      VTHGL=VLHG(15)
      GO TO 110
  130 CALL INT4(TEMP,VLHG,T,V)
      VTHGL=V
```

```
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID VISCOSITY
      ENTRY THGLV(VL,ISTEP,IERR)
      IF(VL.GE.VLHGI(1)) GO TO 150
      VTHGL=TEMPI(1)
  140 CALL PERR(5HTHGLV,ISTEP,VL)
      IERR=1
      RETURN
  150 IF(VL.LE.VLHGI(15)) GO TO 160
      VTHGL=TEMPI(15)
      GO TO 140
  160 CALL INT4(VLHGI,TEMPI,VL,TT)
      VTHGL=TT
      IERR=0
      RETURN
      END
      FUNCTION RTHGG(X)
C     VAPOR DENSITY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), RVHG(16)
      DATA TEMP/250.0,300.0,350.0,400.0,450.0,550.0,650.0,750.0,850.0,
     1 950.0,1000.0,1100.0,1200.0,1300.0,1400.0, 0.0/
      DATA RVHG/ 4.1562E-04,1.3077E-03,3.5473E-03,8.5164E-03,1.8484E-02,
     1 6.8073E-02,1.95465E-01,4.65549E-01,9.60614E-01,1.77210, 2.32558,
     2 3.77786, 5.75378, 8.30564, 11.45475, 0.0/
        ENTRY  RHGGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      RTHGG=RVHG(1)
  110 CALL PERR(6HRHGGT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      RTHGG=RVHG(15)
      GO TO 110
  130 CALL INT4(TEMP,RVHG,T,V)
      RTHGG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR DENSITY
      ENTRY THGGR(RV,ISTEP,IERR)
      IF(RV .GE.RVHG(1)) GO TO 150
      RTHGG=TEMP(1)
  140 CALL PERR(5HTHGGR,ISTEP,RV)
      IERR=1
      RETURN
  150 IF(RV .LE.RVHG(15)) GO TO 160
```

```
      RTHGG=TEMP(15)
      GO TO 140
  160 CALL INT4(RVHG,TEMP,RV,TT)
      RTHGG=TT
      IERR=0
      RETURN
      END
      FUNCTION RTHGL(X)
C     LIQUID DENSITY AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16),RLHG(16),TEMPI(16),RLHGI(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA RLHG/  847.0, 843.0, 834.0, 827.0, 817.0, 809.0, 801.0,
     1     793.0, 784.0, 776.0, 768.0, 761.0, 754.0, 746.0, 739.0, 0.0/
      DATA TEMPI/ 1400.0, 1300.0, 1200.0, 1100.0, 1000.0, 900.0, 800.0,
     1 700.0, 600.0, 500.0, 400.0, 300.0, 200.0, 100.0, 68.0,0.0/
      DATA RLHGI/ 739.0, 746.0, 754.0, 761.0, 768.0, 776.0, 784.0,
     1 793.0, 801.0, 809.0, 817.0, 827.0, 834.0, 843.0, 847.0, 0.0/
        ENTRY  RHGLT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      RTHGL=RLHG(1)
  110 CALL PERR(6HRHGLT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      RTHGL=RLHG(15)
      GO TO 110
  130 CALL INT4(TEMP,RLHG,T,V)
      RTHGL=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID DENSITY
      ENTRY THGLR(RL,ISTEP,IERR)
      IF(RL.GE.RLHGI(1)) GO TO 150
      RTHGL=TEMPI(1)
  140 CALL PERR(5HTHGLR,ISTEP,RL)
      IERR=1
      RETURN
  150 IF(RL.LE.RLHGI(15)) GO TO 160
      RTHGL=TEMPI(15)
      GO TO 140
  160 CALL INT4(RLHGI,TEMPI,RL,TT)
      RTHGL=TT
      IERR=0
      RETURN
```

```
      END
      FUNCTION HTHGG(X)
C     ENTHALPY OF VAPOR AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), HVHG(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA  HVHG/ 132.4, 133.70, 136.20, 138.50, 140.90, 143.30, 145.80,
     1   148.20, 150.60, 153.00, 155.40, 157.80, 160.20, 162.60, 165.00,
     2      0.0/
        ENTRY  HHGGT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      HTHGG=HVHG(1)
  110 CALL PERR(6HHHGGT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      HTHGG=HVHG(15)
      GO TO 110
  130 CALL INT4(TEMP,HVHG,T,V)
      HTHGG=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF VAPOR ENTALPY
      ENTRY THGGH(HV,ISTEP,IERR)
      IF(HV .GE.HVHG(1)) GO TO 150
      HTHGG=TEMP(1)
  140 CALL PERR(5HTHGGH,ISTEP,HV)
      IERR=1
      RETURN
  150 IF(HV .LE.HVHG(15)) GO TO 160
      HTHGG=TEMP(15)
      GO TO 140
  160 CALL INT4(HVHG,TEMP,HV,TT)
      HTHGG=TT
      IERR=0
      RETURN
      END
      FUNCTION HTHGL(X)
C     ENTHALPY OF LIQUID AS A FUNCTION OF TEMP
      DIMENSION TEMP(16), HLHG(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA HLHG/   1.40,   2.40,   5.70,   8.90,  12.00,  15.20,  18.40,
     1    21.80,  25.00,  28.20,  31.50,  34.80,  38.20,  41.60,  44.90,
```

```
     2       0.0/
        ENTRY  HHGLT(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      HTHGL=HLHG(1)
  110 CALL PERR(6HHHGLT ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      HTHGL=HLHG(15)
      GO TO 110
  130 CALL INT4(TEMP,HLHG,T,V)
      HTHGL=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LIQUID ENTHALPY
      ENTRY THGLH(HL,ISTEP,IERR)
      IF(HL .GE.HLHG(1)) GO TO 150
      HTHGL=TEMP(1)
  140 CALL PERR(5HTHGLH,ISTEP,HL)
      IERR=1
      RETURN
  150 IF(HL .LE.HLHG(15)) GO TO 160
      HTHGL=TEMP(15)
      GO TO 140
  160 CALL INT4(HLHG,TEMP,HL,TT)
      HTHGL=TT
      IERR=0
      RETURN
      END
      FUNCTION HTHGE(X)
C     LATENT HEAT OF VAPORIZATION AS A FUNCTION OF TEMP.
      DIMENSION TEMP(16), HFHG(16), TEMPI(16), HFHGI(16)
      DATA TEMP/   68.0,  100.0,  200.0,  300.0,  400.0,  500.0,  600.0,
     1    700.0,  800.0,  900.0, 1000.0, 1100.0, 1200.0, 1300.0, 1400.0,
     2      0.0/
      DATA HFHG/ 131.50, 131.30, 130.50, 129.70, 128.90, 128.10, 127.25,
     1   126.45, 125.60, 124.75, 123.85, 123.00, 122.00, 121.20, 120.10,
     2      0.0/
      DATA TEMPI/ 1400.0, 1300.0, 1200.0, 1100.0, 1000.0, 900.0, 800.0,
     1 700.0, 600.0, 500.0, 400.0, 300.0, 200.0, 100.0, 68.0,0.0/
      DATA HFHGI/ 120.10, 121.20, 122.00, 123.00, 123.85, 124.75,
     1 125.60, 126.45, 127.25, 128.10, 128.90, 129.70, 130.50, 131.30,
     2 131.50, 0.0/
        ENTRY  HHGET(T,ISTEP,IERR)
      IF(T.GE.TEMP(1)) GO TO 120
      HTHGE=HFHG(1)
```

```
  110 CALL PERR(6HHHGET ,ISTEP,T)
      IERR=1
      RETURN
  120 IF(T.LE.TEMP(15)) GO TO 130
      HTHGE=HFHG(15)
      GO TO 110
  130 CALL INT4(TEMP,HFHG,T,V)
      HTHGE=V
      IERR=0
      RETURN
C     TEMPERATURE AS A FUNCTION OF LATENT HEAT OF VAPOR.
      ENTRY THGEH(HF,ISTEP,IERR)
      IF(HF.GE.HFHGI(1)) GO TO 150
      HTHGE=TEMPI(1)
  140 CALL PERR(5HTHGEH,ISTEP,HF)
      IERR=1
      RETURN
  150 IF(HF.LE.HFHGI(15)) GO TO 160
      HTHGE=TEMPI(15)
      GO TO 140
  160 CALL INT4(HFHGI,TEMPI,HF,TT)
      HTHGE=TT
      IERR=0
      RETURN
      END
       SUBROUTINE PERR(FNAME,ISTEP,ARG)
      REAL*8 FNAME
      WRITE (6,1100) FNAME,ISTEP,ARG
 1100 FORMAT(1H0,105(1H*)/
     1    1H0,10X,11HIN CALLING ,A6,   12H AT STEP NO.,I10/
     2    11X,10HARGUMENT (,1PE12.5,25H) IS OUT OF RANGE OF DATA/
     3    11X,41HFUNCTION IS SET TO NEAREST LIMITING VALUE/
     4    1H0,105(1H*))
      RETURN
      END
      FUNCTION EPSR1(R,ISTEP,IERR)
C     SUBROUTINE FOR FINDING EPSILON AS A FUNCTION OF REYNOLDS NUMBER
C     EPS1 = EPSILON RATIO FOR CIRCULAR PIPES
      DIMENSION RE(13), EPS1(13)
      DATA RE/ 2.0E03, 4.0E03, 7.0E03, 1.0E04, 2.0E04, 4.0E04, 7.0E04,
     1 1.0E05, 2.0E05, 4.0E05, 7.0E05, 1.0E06, 0.0/
      DATA EPS1/   10.0,   17.0,   25.0,   34.0,   60.0,  108.0,  175.0,
     1    245.0,  465.0,  900.0,  1550.0,  2250.0,   0.0/
      IF(R.GE.RE(1)) GO TO 110
      EPSR1=EPS1(1)
  100 CALL EPERR(5HEPSR1,ISTEP,R)
```

```
      IERR=1
      RETURN
  110 IF(R.LE.RE(12)) GO TO 120
      EPSR1=EPS1(12)
      GO TO 100
  120 CALL INT4(RE,EPS1,R,S)
      EPSR1=S
      IERR=0
      RETURN
      END
       SUBROUTINE EPERR(FNAME,ISTEP,R)
      WRITE (6,1000) FNAME,ISTEP,R
 1000 FORMAT(1H0,105(1H*)/
     1       1H0,10X,11HIN CALLING ,A6,12H AT STEP NO.,I8/
     2      11X,17HREYNOLDS NUMBER =,1PE12.5,24HIS OUT OF RANGE OF DATA,/
     3       11X,41HFUNCTION IS SET TO NEAREST LIMITING VALUE/
     4       1H0,105(1H*))
       RETURN
      END
      FUNCTION EPSR2(R,ISTEP,IERR)
C     SUBROUTINE FOR FINDING EPSILON AS A FUNCTION OF REYNOLDS NUMBER
C     EPS2 = EPSILON RATIO FOR CONCENTRIC ANNULI
      DIMENSION RE(13), EPS2(13)
      DATA RE/ 2.0E03, 4.0E03, 7.0E03, 1.0E04, 2.0E04, 4.0E04, 7.0E04,
     1 1.0E05, 2.0E05, 4.0E05, 7.0E05, 1.0E06, 0.0/
      DATA EPS2/    6.0,    8.8,    12.8,    17.0,    30.0, 53.0,85.0,
     1    120.0,  230.0,  450.0,  800.0, 1200.0,    0.0/
      IF(R.GE.RE(1)) GO TO 140
      EPSR2=EPS2(1)
  130 CALL EPERR(5HEPSR2,ISTEP,R)
      IERR=1
      RETURN
  140 IF(R.LE.RE(12)) GO TO 150
      EPSR2=EPS2(12)
      GO TO 130
  150 CALL INT4(RE,EPS2,R,S)
      EPSR2=S
      IERR=0
      RETURN
      END
       SUBROUTINE EPERR(FNAME,ISTEP,R)
      WRITE(6,1000) FNAME,ISTEP,R
 1000 FORMAT(1H0,105(1H*)/
     1       1H0,10X,11HIN CALLING ,2A4,12H AT STEP NO.,I8/
     2      11X,17HREYNOLDS NUMBER =,1PE12.5,24HIS OUT OF RANGE OF DATA,/
     3       11X,41HFUNCTION IS SET TO NEAREST LIMITING VALUE/
```

```
4       1H0,105(1H*))
      RETURN
      END
      SUBROUTINE TAB360(/X1/,/X2/,/X3/,
     3                  /X4/,/X5/,/X6/,/X7/,/X8/,/X9/,/X10/,/X11/,/X12/,
     4                  /X13/,/X14/,/X15/,/X16/,/X17/,/X18/,/X19/,/X20/,
     5                  /X21/,/X22/,/ATITLE/)
      DIMENSION     X1(1),    X2(1),    X3(1),    X4(1),    X5(1),
     1              X6(1),    X7(1),    X8(1),    X9(1),    X10(1),
     2              X11(1),   X12(1),   X13(1),   X14(1),   X15(1),
     3              X16(1),   X17(1),   X18(1),   X19(1),   X20(1),
     4              X21(1),   X22(1)
      DIMENSION     ATITLE(1),     TITLE(25)
      DIMENSION     HEADR(102),    HEADR1(34),    HEADR2(34),
     1              HEADR3(34)
      EQUIVALENCE   (HEADR1,HEADR),  (HEADR2,HEADR(35)),
     1              (HEADR3,HEADR(69))
      INTEGER  ALPHA
      DATA  ALPHA/0/
      DATA  BLANK/4H    /,  PERIOD/1H./,  IFTTL/0/,  IFPAGE/0/,
     1      IFTOTL/-1/
      DATA  NSKIP/0/
      ENTRY TABLE (NVAL,/X1/,/X2/,/X3/,/X4/,/X5/,/X6/,/X7/,/X8/,/X9/,
     1             /X10/,/X11/,/X12/,/X13/,/X14/,/X15/,/X16/,/X17/,
     2             /X18/,/X19/,/X20/,/X21/,/X22/)
      ENTRY TABLE1(NVAL,/X1/,/X2/,/X3/,/X4/,/X5/,/X6/,/X7/,/X8/,/X9/,
     1             /X10/,/X11/,/X12/,/X13/,/X14/,/X15/,/X16/,/X17/,
     2             /X18/,/X19/,/X20/,/X21/,/X22/)
      ENTRY TABLE2(NVAL,/X1/,/X2/,/X3/,/X4/,/X5/,/X6/,/X7/,/X8/,/X9/,
     1             /X10/,/X11/,/X12/,/X13/,/X14/,/X15/,/X16/,/X17/,
     2             /X18/,/X19/,/X20/,/X21/,/X22/)
      NROWS=30
      GO TO 300
      ENTRY TABLE3(NVAL,/X1/,/X2/,/X3/,/X4/,/X5/,/X6/,/X7/,/X8/,/X9/,
     1             /X10/,/X11/,/X12/,/X13/,/X14/,/X15/,/X16/,/X17/,
     2             /X18/,/X19/,/X20/,/X21/,/X22/)
      NROWS=40
  300 CONTINUE
      CALL TABSET(NSET,NPAR1,NPAR2,NPAR3,HEADR)
      IF(NSET.GE.1.AND.NSET.LE.3)  GO TO 305
      WRITE(6,9000) NSET
      RETURN
  305 CONTINUE
      NPAGE=IFPAGE-1
      IF(IFTOTL.EQ.0) NTOTAL=((NVAL-1)/NROWS+1)*NSET
      NPAGES=(NVAL-1)/NROWS+1
```

```
      NGRPS=NROWS/5
      LATEST=0
      DO 500 IPAGE=1,NPAGES
      IF(IPAGE.LT.NPAGES) GO TO 320
      NGRPS=(NVAL-LATEST-1)/5+1
  320 CONTINUE
      DO 480 ISET=1,NSET
      NPAGE=NPAGE+1
      IF(NSKIP.NE.0)  GO TO 332
      IF(IFTTL .EQ.1) GO TO 325
      WRITE(6,1000)
      GO TO 330
  325 CONTINUE
      WRITE(6,5000) (TITLE(I),I=1,24)
  330 CONTINUE
      IF(IFPAGE.NE.0)  GO TO 335
  332 CONTINUE
      WRITE(6,4000)
      GO TO 350
  335 CONTINUE
      IF(IFTOTL.LT.0) GO TO 340
      WRITE(6,2000) NPAGE,NPAGES
      GO TO 350
  340 CONTINUE
      WRITE(6,3000) NPAGE
  350 CONTINUE
      GO TO(360,370,380), ISET
  360 CONTINUE
      WRITE(6,HEADR1)
      GO TO 390
  370 CONTINUE
      WRITE(6,HEADR2)
      GO TO 390
  380 CONTINUE
      WRITE(6,HEADR3)
  390 CONTINUE
      INGRP=5
      LAST=LATEST
      DO 450 IGRP=1,NGRPS
      WRITE(6,4000)
      LINE=LAST+1
      L=ALPHA*LAST+1
      LAST=LAST+5
      IF(LAST.GT.NVAL) INGRP=NVAL+5-LAST
      GO TO(400,410,420), ISET
  400 CONTINUE
```

```
      CALL FORPRT(INGRP,NPAR1,ALPHA,X1(L),X2(LINE),X3(LINE),X4(LINE),
     1            X5(LINE),X6(LINE),X7(LINE),X8(LINE),X9(LINE),
     2            X10(LINE))
      GO TO 430
  410 CONTINUE
      IF(NCOLS.EQ.10) GO TO 415
      CALL FORPRT(INGRP,NPAR2,ALPHA,X1(L),X9(LINE),X10(LINE),X11(LINE),
     1            X12(LINE),X13(LINE),X14(LINE),X15(LINE))
      GO TO 430
  415 CONTINUE
      CALL FORPRT(INGRP,NPAR2,ALPHA,X1(L),X11(LINE),X12(LINE),X13(LINE),
     1            X14(LINE),X15(LINE),X16(LINE),X17(LINE),X18(LINE),
     2            X19(LINE))
      GO TO 430
  420 CONTINUE
      IF(NCOLS.EQ.10) GO TO 425
      CALL FORPRT(INGRP,NPAR3,ALPHA,X1(L),X16(LINE),X17(LINE),X18(LINE),
     1            X19(LINE),X20(LINE),X21(LINE),X22(LINE))
      GO TO 430
  425 CONTINUE
      CALL FORPRT(INGRP,NPAR3,ALPHA,X1(L),X20(LINE),X21(LINE),X22(LINE))
  430 CONTINUE
  450 CONTINUE
  480 CONTINUE
      LATEST=LATEST+NROWS
  500 CONTINUE
      RETURN
      ENTRY TTITLE(/ATITLE/)
  600 CONTINUE
      DO 670 I=1,24
      TITLE(I)=BLANK
  670 CONTINUE
      CALL CKSTOR(ATITLE,TITLE)
      IFTTL=1
      RETURN
      ENTRY FINTTL
      IFTTL=0
      RETURN
      ENTRY PAGING(I1,I2)
      IFPAGE=I1
      IFTOTL=I2
      IF(IFTOTL.GT.0)  NTOTAL=IFTOTL
      RETURN
      ENTRY NOPAGE
      IFPAGE=0
      RETURN
```

```
      ENTRY NOSKIP
      NSKIP=1
      RETURN
      ENTRY RESKIP
      NSKIP=0
      RETURN
      ENTRY ALPHAX(K)
      IF(K.LE.0)  GO TO 700
      ALPHA=(MIN0(K,12)-1)/4+1
      RETURN
  700 CONTINUE
      ALPHA=0
      RETURN
 1000 FORMAT(1H1//2H0 )
 2000 FORMAT(1H ,90X,4HPAGE,I4,3H OF,I4)
 3000 FORMAT(1H ,90X,4HPAGE,I4)
 4000 FORMAT(2H  )
 5000 FORMAT(1H1//1H0,5X,24A4)
 9000 FORMAT(1H1//////////1H0,100(1H*)/1H0,25HILLEGAL NO OF PARAMETERS,,
     1        I12,46H, SPECIFIED IN CALL TO SETUP - REQUEST IGNORED/
     2        1H0,100(1H*))
      END
      SUBROUTINE FORPRT(NLINES,NPAR,ALPHA,/P1/,/P2/,/P3/,/P4/,/P5/,/P6/,
     1                  /P7/,/P8/,/P9/,/P10/)
      DIMENSION     P1(1),    P2(1),    P3(1),    P4(1),    P5(1),
     1              P6(1),    P7(1),    P8(1),    P9(1),    P10(1)
      DIMENSION     FORM(160),     F2(8),         F3(8),
     1              OUT(12,5)
      DIMENSION     A4(6)
      EQUIVALENCE  (IX, X)
      INTEGER  ALPHA
      DATA  A4/4H A4,, 4H2A4,, 4H3A4,, 4H9X, , 4H5X, , 4H1X, /
      DATA  FORM(1)/4H(1X,/,  END/4H1X) /
      DATA  CON/4H1X/ /,  TINUE/4H1X, /
      DATA  AI1/4H5X, /,  AI2/4HI8, /,  BLANK/4H    /,  E1/4H1PE1/,
     1      E2/4H3.5,/,  F1/4H OPF/,  QUOTES/1H"/
      DATA  F2/ 4H12.7, 4H11.6, 4H10.5, 4H10.4, 4H10.3, 4H10.2, 4H10.1,
     1          4H10.0 /
      DATA  F3/ 4H,1X,, 4H,2X,, 4H,3X,, 4H,3X,, 4H,3X,, 4H,3X,, 4H,3X,,
     1          4H,3X, /
      INDEX=-1
      KA=0
      DO 400 LINE=1,NLINES
      IF(LINE.EQ.1) GO TO 5
      INDEX=INDEX+2
      FORM(INDEX+2)=TINUE
```

```
  5 CONTINUE
    DO 300 I=1,NPAR
    INDEX=INDEX+3
    GO TO(100,90,80,70,60,50,40,30,20,10),I
 10 CONTINUE
    X=P10(LINE)
    GO TO 110
 20 CONTINUE
    X=P9(LINE)
    GO TO 110
 30 CONTINUE
    X=P8(LINE)
    GO TO 110
 40 CONTINUE
    X=P7(LINE)
    GO TO 110
 50 CONTINUE
    X=P6(LINE)
    GO TO 110
 60 CONTINUE
    X=P5(LINE)
    GO TO 110
 70 CONTINUE
    X=P4(LINE)
    GO TO 110
 80 CONTINUE
    X=P3(LINE)
    GO TO 110
 90 CONTINUE
    X=P2(LINE)
    GO TO 110
100 CONTINUE
    IF(ALPHA.LE.0) GO TO 105
    KADRES=ALPHA*(LINE-1)
    GO TO(103,102,101), ALPHA
101 CONTINUE
    OUT(3,LINE)=P1(KADRES+3)
102 CONTINUE
    OUT(2,LINE)=P1(KADRES+2)
103 CONTINUE
    OUT(1,LINE)=P1(KADRES+1)
    FORM(INDEX)=BLANK
    FORM(INDEX+1)=A4(ALPHA)
    FORM(INDEX+2)=A4(ALPHA+3)
    KA=ALPHA-1
    GO TO 300
```

```
105 CONTINUE
    X=P1(LINE)
110 CONTINUE
    K=I+KA
    OUT(K,LINE)=X
    IF(X) 120,140,130
120 CONTINUE
    X=-X
    CALL BCOMP(1,X,1,QUOTES,IEQUAL)
    IF(IEQUAL) 150,140,150
130 CONTINUE
    IF(IX.GT.1048575) GO TO 150
140 CONTINUE
    FORM(INDEX)=BLANK
    FORM(INDEX+1)=AI2
    FORM(INDEX+2)=AI1
    GO TO 300
150 CONTINUE
    IF(X.GE.1.0E+6)  GO TO 290
    IF(X.LT.0.01)  GO TO 290
    IX=X*100.0
    DO 180 MAG=1,8
    N=MAG
    IX=IX/10
    IF(IX.EQ.0) GO TO 200
180 CONTINUE
200 CONTINUE
280 CONTINUE
    FORM(INDEX)=F1
    FORM(INDEX+1)=F2(N)
    FORM(INDEX+2)=F3(N)
    GO TO 300
290 CONTINUE
    FORM(INDEX)=E1
    FORM(INDEX+1)=E2
    FORM(INDEX+2)=BLANK
300 CONTINUE
    IF(LINE.LT.NLINES)  GO TO 310
    FORM(INDEX+3)=END
    GO TO 400
310 CONTINUE
    FORM(INDEX+3)=CON
400 CONTINUE
    INDEX=INDEX+4
    IF(INDEX.GT.160)  GO TO 460
    DO 450 J=INDEX,160
```

```
      FORM(J)=BLANK
  450 CONTINUE
  460 CONTINUE
      WRITE(6,FORM) ((OUT(I,J),I=1,K),J=1,NLINES)
  500 CONTINUE
      RETURN
      END
00108-20-70  CST/PCS-G DOUBLE CONTAINMENT BOILER (BRDC NO.5), 12 TUBES, RUN 2
101          13555.        148.        353.        1165.        1185.
102              0.0         5.          .652         .049         .100
103               .049    3000.         12.          15.          39.2
104              1.           .01         .01         25.         210.
105            150.          6.          .080         .032        12.
106             16.         51.          .020        0.0           .5
107              1.          0.0         2.           .001         .88
108               .05        3.         10.           .1          41.
109              0.0                 1           0            1     0.0
110              0.0         0.0         1.           .6      57148.
00108-20-70  CST/PCS-G DOUBLE CONTAINMENT BOILER (BRDC NO.5), 12 TUBES, RUN 2A
101          13383.        145.        353.        1190.        1210.
102              0.0         5.          .652         .049         .100
103               .049    3000.         12.          15.          39.2
104              1.           .01         .01         25.         210.
105            150.          6.          .080         .032        12.
106             16.         51.          .020        2.7           .5
107              1.          0.0         2.           .001         .88
108               .05        3.         10.           .1          41.
109             21.5                 1           0            1     0.0
110              0.0         0.0         1.           .6      57148.
  0
```

APPENDIX B

OUTPUT - SAMPLE PROBLEM

NOMENCLATURE

BOUNDARY	-	Superheat section boundary number,
DTFILM	-	Temperature difference, wall-to-bulk Hg, °F,
DTNHG	-	Temperature difference, NaK-to-Hg, °F,
DTSS	-	Temperature drop across stailess steel wall, °F,
DTSTAG	-	Temperature drop across stagnant NaK, °F,
DTTA	-	Temperature drop across Ta wall, °F,
H	-	Hg side film conductance, Btu/hr-ft^2-°F,
LENGTH	-	Boiler length from NaK exit point, ft,
LIQ FILM	-	Liquid film thickness, inches,
Nu	-	Nusselt modulus,
P	-	Pressure, psia,
PE	-	Peclet modulus,
PH	-	Preheat section length, ft,
PHBOND	-	Preheat section boundary number,
PHI	-	Two-phase flow pressure drop factor,
PR	-	Prandtl modulus,
QFLUX	-	Heat flux, Btu/hr-ft^2,
RE	-	Reynold's modulus,
REVAP	-	Reynold's modulus, vapor only,
RO	-	Nandimmensional liquid film thickness in divided two-phase flow regime,
THAK	-	Temperature, NaK, °F,
THG	-	Temperature, Hg, °F,
T1	-	Ta tube inside wall temperature, °F,
T2	-	Ta tube outside wall temperature, °F,
T3	-	Stagnant NaK containment tube (SS) inside wall temperature, °F,
T4	-	Stagnant NaK containment tube (SS) outside wall temperature, °F,
U	-	Conductance NaK-to-Hg, Btu/hr-ft^2-°F,
XP	-	Vapor quality boundary increments in plug insert section,
XWET	-	Vapor quality boundary increments,

$$XX = \frac{\bar{x}\,\rho_o\mu_1}{(1 - \bar{x})\rho_1\mu_o}$$ - Eq 12a, Appendix C,

$$XXX = \frac{\bar{x}\,\rho_o\mu_1}{(1 - \bar{x})\rho_1\mu_o}$$ - Ea 26, Appendix C,

$$YY = \frac{N_1 \, r_o \, \mu_1}{12 \, \bar{x} \, W_{TOT}}$$ - Eq 12b, Appendix C,

$$YYY = \frac{N_1 \, N_2 \, r_o \, \mu_1}{12 \, \bar{x} \, W_{TOT}}$$ - Eq 27, Appendix C,

ZETA - Frictional pressure drop coefficient,

ZETALIN - Linear frictional pressure drop coefficient,

ZETATAN - Tangentional frictional pressure drop coefficient.

SNAP-8 BODEPE COMPUTER PROGRAM - BOILER DESIGN AND PERFORMANCE ANALYSIS OUTPUT 1

DATE 08-26-08 SNAP-8 TA-SS DOUBLE CONTAINMENT BOILER,MPP+SFHX,BODE,LO.

S U M M A R Y

	LENGTH FT	INLET PRESSURE PSIA	PRESSURE DROP PSI	MEAN HEAT FLUX B/H-SQFT	NAK TEMP SECT.IN DEG.F	HG TEMP SECT.IN DEG.F	MASS VELOCITY LB/S-SQFT	HEAT INPUT B/HR	X EXIT
MPPPH SECTION	0.9	310.9	0.5	214451.	1110.	500.	830.9	230742.	0.0
MPPXP SECTION	2.7	310.5	19.3	53442.	1134.	1099.	830.9	174216.	0.12
SFHXX SECTION	15.4	291.2	19.8	67434.	1151.	1086.	238.4	1278692.	1.00
SFHXSH SECTION	6.5	271.4	10.3	6920.	1277.	1073.	238.4	55280.	
EXCESSH SECTION	0.0	261.1	0.0		1283.	1260.	238.4		
TOTAL BOILER	25.5	* 261.1	49.9		* 1283.	* 1260.		1738930.	

* - EXIT PARAMETERS

NAK FLOW TOTAL LB/HR	NAK FLOW NET LB/HR	MERCURY FLOW LB/HR	ENTHALPY CHANGE NAK BTU/LB	ENTHALPY CHANGE HG BTU/LB	THERMAL POWER KW	HEAT LOSS EXTERNAL KW	PINCH POINT DT DEG.F	TERMINAL NAK-HG DT DEG.F	VAPOR SUPERHEAT DEG.F
48184.	47070.	11800.	37.	147.	527.	12.	35.8	22.8	195.

THERMAL PASS RESISTANCES,MATERIAL CONDUCTIVITIES AND HG PASSAGE GEOMETRY

RCNF = 0.000228	HR-SQFT-DEG.F/BTU	NAK FILM	D1 = 0.670	INCH	HG TUBE ID
RCNT = 0.000159	HR-SQFT-DEG.F/BTU	SS TUBE	TTA = 0.040	INCH	TA WALL THICKNESS
RCST = 0.000360	HR-SQFT-DEG.F/BTU	STAGNANT NAK	TST = 0.080	INCH	STAGN.NAK THICKNESS(MEAN)
RCHT = 0.000079	HR-SQFT-DEG.F/BTU	TA TUBE	TSS = 0.035	INCH	SS WALL THICKNESS
RR = 0.000826	HR-SQFT-DEG.F/BTU	TOTAL OF ABOVE	D2 = 0.980	INCH	HG TUBE OD.

PMPP = 6.000	INCH	MPP PITCH	KSS =13.00	BTU/HR-FT-DEG.F		CONDUCTIVITY,SS
N2 = 16.		NUMBER OF PASSAGES IN MPP	KNAK =15.00	BTU/HR-FT-DEG.F		CONDUCTIVITY,NAK
DMPP = 0.080	INCH	PASSAGE WIDTH	KTA =40.00	BTU/HR-FT-DEG.F		CONDUCTIVITY,TA
HMPP = 0.032	INCH	PASSAGE HEIGTH(1)	DEMPP= 0.0752		INCH	DIA.EQ.,MPP
HHMPP = 0.072	INCH	PASSAGE HEIGTH(2)	ACMPP= 0.0051		SQINCH	CROSSECT.AREA
PHELIX= 3.000	INCH	SFHX PITCH	DEH = 0.4016		INCH	DIA.EQ.,SFHX
THICK = 0.030	INCH	SFHX STRIP THICKNESS	AH = 0.2828		SQINCH	CROSSECT.AREA
DBAR = 0.1875	INCH	CENTER BAR OD	N1 = 7.			NUMBER OF TUBES

DATE 08-26-08 SNAP-8 TA-SS DOUBLE CONTAINMENT BOILER,MPP+SFHX,BODE,LO.

PH SECTION

PHECNO	TNAK	THG	P	LENGTH	QFLUX	U	DTNHG
1	1110.00	500.000	310.937	0	627162.	1040.38	602.822
2	1110.58	514.966	310.934	7.30950E-03	612915.	1041.59	588.440
3	1111.17	529.932	310.930	0.0147500	598620.	1042.79	574.057
4	1111.75	544.898	310.926	0.0223612	584272.	1043.95	559.676
5	1112.33	559.864	310.921	0.0301846	569869.	1045.06	545.298
6	1112.92	574.830	310.917	0.0382660	555407.	1046.11	530.927
7	1113.52	589.796	310.913	0.0466541	540886.	1047.08	516.565
8	1114.13	604.762	310.908	0.0554060	526306.	1047.97	502.214
9	1114.75	619.729	310.903	0.0645973	511672.	1048.78	487.875
10	1115.38	634.695	310.898	0.0742046	496994.	1049.52	473.544
11	1116.02	649.661	310.893	0.0841749	482280.	1050.23	459.216
12	1116.66	664.627	310.888	0.0944512	467537.	1050.91	444.886
13	1117.29	679.593	310.882	0.104970	452768.	1051.60	430.551
14	1117.92	694.559	310.876	0.115664	437977.	1052.31	416.206
15	1118.53	709.525	310.871	0.126482	423158.	1053.02	401.850
16	1119.14	724.491	310.865	0.137499	408308.	1053.73	387.487
17	1119.74	739.457	310.859	0.148783	393431.	1054.44	373.120
18	1120.33	754.423	310.853	0.160405	378529.	1055.13	358.750
19	1120.93	769.389	310.847	0.172442	363604.	1055.82	344.380
20	1121.52	784.355	310.840	0.184983	348660.	1056.51	330.012
21	1122.12	799.321	310.833	0.198127	333696.	1057.19	315.646
22	1122.72	814.287	310.826	0.211894	318712.	1057.86	301.281
23	1123.32	829.253	310.819	0.226270	303706.	1058.52	286.915
24	1123.92	844.219	310.811	0.241348	288681.	1059.19	272.550
25	1124.53	859.186	310.802	0.257234	273636.	1059.84	258.187
26	1125.13	874.152	310.794	0.274056	258575.	1060.49	243.826
27	1125.74	889.118	310.784	0.291959	243498.	1061.13	229.469
28	1126.35	904.084	310.774	0.311118	228405.	1061.77	215.117
29	1126.96	919.050	310.764	0.331715	213298.	1062.40	200.770
30	1127.58	934.016	310.752	0.353915	198175.	1063.02	186.426

PNBCNO	H	DTFILM	RF	PR	NU	PE	ZETA
1	7377.23	85.0131	8217.05	0.0111694	7.00000	91.7793	0.0331901
2	7438.80	82.3943	8300.73	0.0109635	7.00000	91.0047	0.0331061
3	7500.18	79.8140	8382.89	0.0107660	7.00000	90.2503	0.0330247
4	7560.61	77.2785	8463.67	0.0105775	7.00000	89.5244	0.0329456
5	7619.28	74.7930	8542.28	0.0103994	7.00000	88.8347	0.0328695
6	7675.41	72.3618	8618.49	0.0102324	7.00000	88.1883	0.0327966
7	7728.23	69.9884	8692.58	0.0100766	7.00000	87.5919	0.0327265
8	7776.86	67.6759	8764.84	9.93211E-03	7.00000	87.0533	0.0326589
9	7821.41	65.4194	8835.59	9.79783E-03	7.00000	86.5696	0.0325933
10	7863.01	63.2066	8905.18	9.67158E-03	7.00000	86.1272	0.0325294
11	7902.77	61.0267	8973.75	9.55153E-03	7.00000	85.7130	0.0324671
12	7941.82	58.8703	9039.51	9.43799E-03	7.00000	85.3148	0.0324079
13	7981.27	56.7288	9102.67	9.32916E-03	7.00000	84.9203	0.0323515
14	8022.23	54.5954	9164.05	9.22279E-03	7.00000	84.5182	0.0322972
15	8064.01	52.4748	9224.53	9.11876E-03	7.00000	84.1163	0.0322442
16	8105.79	50.3725	9285.03	9.01697E-03	7.00000	83.7228	0.0321915
17	8147.56	48.2882	9346.53	8.91641E-03	7.00000	83.3375	0.0321384
18	8189.33	46.2222	9409.53	8.81658E-03	7.00000	82.9599	0.0320845
19	8231.11	44.1743	9473.24	8.71820E-03	7.00000	82.5895	0.0320304
20	8272.88	42.1449	9537.18	8.62164E-03	7.00000	82.2262	0.0319766
21	8314.66	40.1335	9600.91	8.52726E-03	7.00000	81.8695	0.0319234
22	8356.43	38.1397	9663.91	8.43538E-03	7.00000	81.5188	0.0318712
23	8398.20	36.1633	9725.70	8.34641E-03	7.00000	81.1746	0.0318205
24	8439.98	34.2040	9785.73	8.26073E-03	7.00000	80.8373	0.0317716
25	8481.76	32.2618	9844.20	8.17814E-03	7.00000	80.5072	0.0317243
26	8523.53	30.3366	9901.38	8.09835E-03	7.00000	80.1848	0.0316784
27	8565.30	28.4284	9957.27	8.02131E-03	7.00000	79.8704	0.0316338
28	8607.01	26.5371	10011.9	7.94717E-03	7.00000	79.5661	0.0315906
29	8648.56	24.6628	10065.2	7.87604E-03	7.00000	79.2739	0.0315487
30	8690.06	22.8048	10117.2	7.80751E-03	7.00000	78.9903	0.0315081

PHBCNO	TNAK	THG	P	LENGTH	QFLUX	U	DTNHG
31	1128.21	948.982	310.740	0.377916	183036.	1063.64	172.083
32	1128.83	963.548	310.726	0.403963	167879.	1064.26	157.742
33	1129.46	978.914	310.712	0.432374	152704.	1064.88	143.400
34	1130.08	993.880	310.696	0.463555	137509.	1065.49	129.057
35	1130.70	1008.85	310.678	0.498059	122295.	1066.11	114.712
36	1131.32	1023.81	310.658	0.536727	107063.	1066.73	100.365
37	1131.94	1038.78	310.635	0.580841	91812.0	1067.35	86.0183
38	1132.56	1053.74	310.608	0.632320	76543.4	1067.97	71.6719
39	1133.18	1068.71	310.576	0.694240	61259.3	1068.58	57.3279
40	1133.80	1083.68	310.536	0.771983	45959.9	1069.18	42.9863
41	1134.43	1098.64	310.483	0.876308	0	0	0

PHECNO	H	DTFILM	RE	PR	NU	PE	ZETA
31	8731.62	20.9624	10167.8	7.74126E-03	7.00000	78.7119	0.0314688
32	8773.36	19.1351	10216.1	7.67761E-03	7.00000	78.4352	0.0314315
33	8815.39	17.3224	10262.3	7.61592E-03	7.00000	78.1567	0.0313961
34	8857.80	15.5241	10307.0	7.55535E-03	7.00000	77.8732	0.0313620
35	8900.81	13.7398	10351.0	7.49547E-03	7.00000	77.5856	0.0313286
36	8944.32	11.9699	10394.9	7.43606E-03	7.00000	77.2968	0.0312955
37	8988.11	10.2148	10439.3	7.37667E-03	7.00000	77.0074	0.0312622
38	9031.95	8.47473	10484.7	7.31720E-03	7.00000	76.7183	0.0312283
39	9075.64	6.74986	10530.1	7.25828E-03	7.00000	76.4303	0.0311946
40	9118.92	5.04006	10575.5	7.20005E-03	7.00000	76.1439	0.0311611
41	0	0	0	0	0	0	0

PHLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	DTSS
0	967.380	867.573	641.866	592.495	49.3711	225.707	99.8074
7.30950E-03	971.211	873.671	653.091	604.842	48.2495	220.579	97.5400
0.0147500	975.052	879.787	664.352	617.228	47.1243	215.435	95.2651
0.0223612	978.906	885.925	675.653	629.658	45.9949	210.271	92.9819
0.0301846	982.777	892.088	687.000	642.139	44.8608	205.087	90.6897
0.0382660	986.668	898.280	698.396	654.674	43.7224	199.883	88.3882
0.0466541	990.581	904.503	709.846	667.267	42.5793	194.657	86.0774
0.0554060	994.519	910.762	721.352	679.920	41.4316	189.410	83.7568
0.0645973	998.481	917.053	732.909	692.630	40.2795	184.143	81.4280
0.0742046	1002.46	923.368	744.507	705.383	39.1240	178.861	79.0923
0.0841749	1006.45	929.701	756.135	718.170	37.9658	173.566	76.7507
0.0944512	1010.45	936.044	767.784	730.979	36.8052	168.260	74.4043
0.104970	1014.44	942.391	779.446	743.804	35.6426	162.945	72.0540
0.115664	1018.44	948.736	791.115	756.636	34.4783	157.622	69.7002
0.126482	1022.42	955.082	802.794	769.482	33.3115	152.288	67.3418
0.137499	1026.41	961.432	814.488	782.345	32.1426	146.944	64.9788
0.148783	1030.40	967.789	826.199	795.228	30.9714	141.590	62.6111
0.160405	1034.39	974.153	837.926	808.128	29.7983	136.227	60.2395
0.172442	1038.39	980.525	849.669	821.045	28.6235	130.856	57.8645
0.184983	1042.39	986.907	861.429	833.982	27.4470	125.478	55.4863
0.198127	1046.40	993.299	873.206	846.937	26.2690	120.092	53.1047
0.211894	1050.42	999.699	884.999	859.909	25.0896	114.700	50.7202
0.226270	1054.44	1006.11	896.807	872.899	23.9082	109.300	48.3323
0.241348	1058.46	1012.52	908.631	885.906	22.7253	103.892	45.9412
0.257234	1062.50	1018.95	920.471	898.930	21.5410	98.4778	43.5469
0.274056	1066.53	1025.38	932.326	911.970	20.3555	93.0574	41.1499
0.291959	1070.58	1031.83	944.197	925.028	19.1685	87.6313	38.7507
0.311118	1074.63	1038.28	956.083	938.103	17.9805	82.2000	36.3489
0.331715	1078.69	1044.75	967.986	951.195	16.7913	76.7629	33.9446
0.353915	1082.76	1051.22	979.904	964.303	15.6006	71.3203	31.5378

PHLENGTH	CTTOTAL
0	374.885
7.30950E-03	366.369
0.0147500	357.824
0.0223612	349.248
0.0301846	340.638
0.0382660	331.994
0.0466541	323.314
0.0554060	314.598
0.0645973	305.851
0.0742046	297.077
0.0841749	288.282
0.0944512	279.469
0.1049700	270.641
0.115664	261.800
0.126482	252.942
0.137499	244.066
0.148783	235.173
0.160405	226.265
0.172442	217.344
0.184983	208.411
0.198127	199.466
0.211894	190.510
0.226270	181.540
0.241348	172.559
0.257234	163.566
0.274056	154.563
0.291959	145.551
0.311118	136.529
0.331715	127.499
0.353915	118.459

FHLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	DTSS
0.377916	1086.84	1057.71	991.835	977.427	14.4089	65.8718	29.1287
0.403963	1090.91	1064.20	1003.78	990.565	13.2158	60.4172	26.7166
0.432374	1095.00	1070.70	1015.74	1003.72	12.0212	54.9558	24.3015
0.463555	1099.08	1077.20	1027.71	1016.89	10.8250	49.4878	21.8835
0.498059	1103.17	1083.71	1039.70	1030.07	9.62744	44.0125	19.4624
0.536727	1107.26	1090.22	1051.69	1043.26	8.42822	38.5305	17.0381
0.580841	1111.36	1096.75	1063.70	1056.48	7.22754	33.0420	14.6111
0.632320	1115.46	1103.27	1075.73	1069.70	6.02563	27.5469	12.1814
0.694240	1119.56	1109.81	1087.77	1082.94	4.82251	22.0464	9.74902
0.771983	1123.67	1116.36	1099.82	1096.20	3.61816	16.5405	7.31421
0.876308	0	0	0	0	0	0	0

PHLENGTH	CTTOTAL
0.377916	109.409
0.403963	100.350
0.432374	91.2786
0.463555	82.1963
0.498059	73.1023
0.536727	63.9968
0.580841	54.8806
0.632320	45.7539
0.694240	36.6179
0.771983	27.4729
0.876308	0

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XP SECTION

XP	TNAK	THG	P	LENGTH	QFLUX	U	DTNHG
C	1134.43	1098.68	310.483	0.876308	41682.1	1120.56	37.1975
C.0200000	1137.27	1098.60	310.353	1.44355	47127.8	1176.68	40.0515
C.0400000	1140.04	1098.07	309.510	1.94525	51590.9	1190.06	43.3516
C.0600000	1142.80	1096.76	307.455	2.40357	56715.7	1196.08	47.4180
0.0800000	1145.56	1094.45	303.839	2.82051	62962.8	1199.52	52.4897
C.1000000	1148.31	1090.96	298.455	3.19615	70582.6	1201.77	58.7324
0.120000	1151.07	1086.19	291.213	3.53132	0	0	0

XP	F	DTFILM	NU	XXX	YYY	PHI	ZETA
0	14976.4	2.78318	102.140	0.277159	6.34779E-03	11.4103	0.0597409
0.0200000	41303.8	1.14100	281.701	0.848826	2.11569E-03	12.2762	0.0453921
0.0400000	68226.2	0.756174	465.397	1.44679	1.26848E-03	13.3597	0.0399427
0.0600000	95912.2	0.591329	654.520	2.07710	9.04436E-04	14.2654	0.0367038
0.0800000	124603.	0.505308	850.926	2.74812	7.01213E-04	15.0404	0.0344413
0.1000000	154530.	0.456757	1056.46	3.47019	5.70970E-04	15.7239	0.0327167
0.120000	0	0	0	0	0	0	0

XP	RC	LIQ FILM	RE
C	0.980419	6.55961E-03	782.817
0.0200000	0.992900	2.37840E-03	2348.71
C.0400000	0.995703	1.43963E-03	3917.40
0.0600000	0.996944	1.02365E-03	5494.20
C.0800000	0.997650	7.87377E-04	7086.51
C.1000000	0.998107	6.34193E-04	8703.00
C.120000	0	C	0

XPLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	TSS
0.876308	1126.38	1119.75	1104.75	1101.46	3.28125	15.0010	6.63354
1.44355	1127.91	1120.41	1103.45	1099.74	3.70996	16.9607	7.50000
1.94525	1129.66	1121.45	1102.88	1098.82	4.06152	18.5669	8.21045
2.40357	1131.25	1122.23	1101.82	1097.35	4.46484	20.4111	9.02588
2.82051	1132.59	1122.57	1099.91	1094.95	4.95654	22.6594	10.0200
3.19615	1133.61	1122.37	1096.97	1091.42	5.55640	25.4016	11.2327
3.53132	0	0	0	0	0	0	0

XPLENGTH	DTTOTAL
0.876308	24.9158
1.44355	28.1707
1.94525	30.8389
2.40357	33.9019
2.82051	37.6360
3.19615	42.1907
3.53132	0

DATE 08-26-08 SNAP-8 TA-SS DOUBLE CONTAINMENT BOILER,MPP+SFHX,BODE,LO.

SFHXX SECTION

XWET	THAK	THG	P	LENGTH	QFLUX	U	DTNHG
0.120000	1151.07	1086.19	291.213	3.53132	75424.9	1137.56	66.3040
0.140000	1153.87	1086.17	291.191	3.84509	79197.2	1146.60	69.0713
0.160000	1156.62	1086.15	291.164	4.14390	82896.8	1153.89	71.8411
0.180000	1159.37	1086.13	291.132	4.42939	86540.6	1159.81	74.6160
0.200000	1162.12	1086.11	291.095	4.70285	90151.4	1164.83	77.3943
0.220000	1164.88	1086.08	291.053	4.96536	93732.9	1169.04	80.1794
0.240000	1167.64	1086.05	291.005	5.21784	97300.7	1172.70	82.9714
0.260000	1170.40	1086.01	290.953	5.46106	100856.	1175.87	85.7720
0.280000	1173.17	1085.97	290.894	5.69571	104406.	1178.64	88.5813
0.300000	1175.94	1085.93	290.830	5.92238	107953.	1181.08	91.4014
0.320000	1178.72	1085.88	290.760	6.14160	111506.	1183.30	94.2334
0.340000	1181.51	1085.83	290.685	6.35384	115062.	1185.26	97.0771
0.360000	1184.31	1085.78	290.603	6.55952	118628.	1187.05	99.9346
0.380000	1187.12	1085.72	290.515	6.75902	122203.	1188.67	102.806
0.400000	1189.94	1085.66	290.421	6.95268	125791.	1190.15	105.694
0.420000	1192.77	1085.59	290.321	7.14082	129394.	1191.50	108.598
0.440000	1195.61	1085.52	290.215	7.32373	133014.	1192.74	111.520
0.460000	1198.47	1085.45	290.102	7.50165	136651.	1193.89	114.459
0.480000	1201.34	1085.37	289.984	7.67484	140304.	1194.96	117.414
0.500000	1204.22	1085.28	289.859	7.84352	143963.	1195.96	120.375
0.520000	1207.10	1085.20	289.727	8.00792	147629.	1196.88	123.344
0.540000	1209.98	1085.10	289.590	8.16823	151303.	1197.75	126.322
0.560000	1212.87	1085.01	289.445	8.32466	154983.	1198.56	129.308
0.580000	1215.76	1084.91	289.295	8.47737	158674.	1199.34	132.302
0.599999	1218.65	1084.80	289.138	8.62653	162372.	1200.06	135.303
0.619999	1221.55	1084.69	288.974	8.77229	166078.	1200.75	138.313
0.639999	1224.45	1084.58	288.804	8.91480	169793.	1201.40	141.329
0.659999	1227.36	1084.46	288.628	9.05419	173517.	1202.02	144.354
0.679999	1230.27	1084.34	288.445	9.19060	177251.	1202.61	147.388
0.699999	1233.18	1084.21	288.255	9.32413	180995.	1203.18	150.431

XWET	H	DTFILM	NU	XX	YY	PHI	ZETA
0.120000	18714.7	4.03025	76.7998	4.25572	2.99974E-05	2.38434	0.0314783
0.140000	21503.4	3.68302	88.2440	5.02621	2.59973E-05	2.31121	0.0307510
0.160000	24393.7	3.39829	100.106	5.83395	2.29382E-05	2.25925	0.0301359
0.180000	27345.2	3.16475	112.219	6.68172	2.05230E-05	2.22237	0.0296051
0.200000	30437.4	2.96186	124.909	7.57257	1.85678E-05	2.19426	0.0291399
0.220000	33596.1	2.78999	137.873	8.50991	1.69526E-05	2.17382	0.0287270
0.240000	36908.8	2.63625	151.470	9.49746	1.55957E-05	2.15784	0.0283567
0.260000	40325.8	2.50104	165.495	10.5394	1.44398E-05	2.14592	0.0280217
0.280000	43870.4	2.37987	180.044	11.6403	1.34432E-05	2.13693	0.0277163
0.300000	47525.5	2.27147	195.047	12.8054	1.25752E-05	2.13038	0.0274361
0.320000	51400.3	2.16937	210.952	14.0404	1.18123E-05	2.12513	0.0271776
0.340000	55380.7	2.07765	227.292	15.3519	1.11365E-05	2.12163	0.0269380
0.360000	59581.2	1.99103	244.536	16.7471	1.05337E-05	2.11904	0.0267149
0.380000	63955.2	1.91076	262.493	18.2343	9.99273E-06	2.11744	0.0265063
0.400000	68528.6	1.83560	281.269	19.8229	9.50446E-06	2.11662	0.0263106
0.420000	73298.2	1.76531	300.852	21.5237	9.06156E-06	2.11649	0.0261265
0.440000	78331.0	1.69810	321.516	23.3488	8.65797E-06	2.11679	0.0259528
0.460000	83592.5	1.63473	343.120	25.3125	8.28870E-06	2.11759	0.0257884
0.480000	89193.4	1.57303	366.120	27.4310	7.94950E-06	2.11860	0.0256325
0.500000	95125.4	1.51341	390.479	29.7234	7.63688E-06	2.11988	0.0254844
0.520000	101363.	1.45643	416.097	32.2119	7.34781E-06	2.12148	0.0253433
0.540000	107988.	1.40110	443.305	34.9227	7.07970E-06	2.12326	0.0252086
0.560000	114985.	1.34786	472.042	37.8870	6.83039E-06	2.12527	0.0250799
0.580000	122637.	1.29385	503.474	41.1418	6.59794E-06	2.12720	0.0249567
0.599999	130663.	1.24268	536.439	44.7319	6.38068E-06	2.12942	0.0248386
0.619999	139308.	1.19217	571.950	48.7117	6.17718E-06	2.13169	0.0247252
0.639999	148710.	1.14177	610.577	53.1482	5.98618E-06	2.13397	0.0246162
0.659999	158815.	1.09257	652.090	58.1244	5.80654E-06	2.13635	0.0245112
0.679999	169943.	1.04301	697.806	63.7448	5.63727E-06	2.13869	0.0244101
0.699999	182051.	0.994201	747.555	70.1429	5.47752E-06	2.14109	0.0243125

XWET	ZETALIN	ZETATAN	RO	LIQ FILM	RE VAP
0.120000	0.0206920	0.0107863	0.921875	0.0261719	15857.0
0.140000	0.0199647	0.0107863	0.932007	0.0227777	18296.9
0.160000	0.0193495	0.0107863	0.940063	0.0200788	20737.0
0.180000	0.0188188	0.0107863	0.946533	0.0179114	23177.3
0.200000	0.0183536	0.0107863	0.951965	0.0160916	25617.9
0.220000	0.0179407	0.0107863	0.956482	0.0145786	28058.8
0.240000	0.0175704	0.0107863	0.960388	0.0132700	30500.0
0.260000	0.0172354	0.0107863	0.963745	0.0121454	32941.6
0.280000	0.0169300	0.0107863	0.966675	0.0111639	35383.6
0.300000	0.0166498	0.0107863	0.969238	0.0103052	37826.1
0.320000	0.0163913	0.0107863	0.971558	9.52822E-03	40269.1
0.340000	0.0161517	0.0107863	0.973602	8.84324E-03	42712.6
0.360000	0.0159286	0.0107863	0.975464	8.21966E-03	45156.7
0.380000	0.0157200	0.0107863	0.977142	7.65735E-03	47601.5
0.400000	0.0155243	0.0107863	0.978668	7.14618E-03	50046.9
0.420000	0.0153402	0.0107863	0.980057	6.68103E-03	52493.1
0.440000	0.0151665	0.0107863	0.981339	6.25163E-03	54940.0
0.460000	0.0150021	0.0107863	0.982513	5.85800E-03	57387.7
0.480000	0.0148462	0.0107863	0.983612	5.49001E-03	59836.3
0.500000	0.0146981	0.0107863	0.984634	5.14752E-03	62285.8
0.520000	0.0145569	0.0107863	0.985580	4.83060E-03	64736.2
0.540000	0.0144223	0.0107863	0.986465	4.53413E-03	67187.7
0.560000	0.0142936	0.0107863	0.987289	4.25810E-03	69640.1
0.580000	0.0141704	0.0107863	0.988083	3.99226E-03	72093.6
0.599999	0.0140523	0.0107863	0.988815	3.74693E-03	74548.3
0.619999	0.0139389	0.0107863	0.989510	3.51429E-03	77004.2
0.639999	0.0138299	0.0107863	0.990173	3.29196E-03	79461.2
0.659999	0.0137249	0.0107863	0.990799	3.08239E-03	81919.6
0.679999	0.0136238	0.0107863	0.991402	2.88045E-03	84379.4
0.699999	0.0135262	0.0107863	0.991974	2.68877E-03	86840.4

XWET	THAK	THG	P	LENGTH	QFLUX	U	DTNHG
0.719999	1236.10	1084.08	288.059	9.45490	184749.	1203.72	153.481
0.739999	1239.02	1083.94	287.856	9.58301	188513.	1204.25	156.540
0.759999	1241.95	1083.80	287.647	9.70857	192290.	1204.75	159.609
0.779999	1244.87	1083.65	287.431	9.83166	196077.	1205.25	162.686
0.799999	1247.81	1083.50	287.209	9.95238	199876.	1205.72	165.773
0.819999	1250.75	1083.35	286.980	10.0708	203687.	1206.19	168.868
0.839999	1253.69	1083.19	286.745	10.1870	207510.	1206.66	171.970
0.859999	1256.64	1083.03	286.503	10.3011	211345.	1207.11	175.083
0.879999	1259.59	1082.86	286.254	10.4131	26288.2	147.518	178.203
0.899999	1262.54	1081.57	284.345	11.3135	24306.2	133.219	182.453
0.919999	1265.50	1080.22	282.373	12.2875	21885.9	117.189	186.758
0.939999	1268.47	1078.76	280.238	13.3693	18863.3	98.6668	191.187
0.959999	1271.43	1077.15	277.900	14.6245	14843.8	75.8225	195.770
0.979999	1274.41	1075.25	275.167	16.2198	8596.54	42.8446	200.645
1.00000	1277.39	1072.61	271.404	18.9748	0	0	0

XWFT	F	DTFILM	NU	XX	YY	PHI	ZETA
0.719999	195416.	0.945415	802.470	77.4915	5.32648E-06	2.14348	0.0242183
0.739999	210209.	0.896787	863.255	86.0188	5.18346E-06	2.14588	0.0241272
0.759999	226887.	0.847515	931.784	96.0326	5.04784E-06	2.14821	0.0240391
0.779999	245805.	0.797693	1009.53	107.957	4.91907E-06	2.15049	0.0239538
0.799999	267416.	0.747435	1098.34	122.397	4.79662E-06	2.15273	0.0238710
0.819999	292757.	0.695755	1202.47	140.239	4.68004E-06	2.15487	0.0237908
0.839999	322859.	0.642724	1326.18	162.845	4.56891E-06	2.15689	0.0237129
0.859999	359172.	0.588421	1475.42	192.414	4.46287E-06	2.15883	0.0236372
0.879999	167.977	156.501	655.659	0	0	1.97593	0.0235637
0.899999	149.682	162.360	585.151	0	0	1.80148	0.0234872
0.919999	129.742	168.708	508.012	0	0	1.67529	0.0234125
0.939999	107.417	175.543	421.333	0	0	1.51002	0.0233392
0.959999	80.8862	183.600	317.878	0	0	1.32624	0.0232670
0.979999	44.4157	193.365	174.947	0	0	1.00940	0.0231953
1.00000	0	0	0	0	0	0	0

XWET	ZETALIN	ZETATAN	RO	LIQ FILM	RE VAP
0.719999	0.0134320	0.0107863	0.992523	2.50477E-03	89302.8
0.739999	0.0133409	0.0107863	0.993050	2.32840E-03	91766.7
0.759999	0.0132528	0.0107863	0.993561	2.15715E-03	94232.2
0.779999	0.0131674	0.0107863	0.994057	1.99103E-03	96699.1
0.799999	0.0130847	0.0107863	0.994537	1.83004E-03	99167.7
0.819999	0.0130045	0.0107863	0.995010	1.67155E-03	101638.
0.839999	0.0129266	0.0107863	0.995476	1.51563E-03	104110.
0.859999	0.0128509	0.0107863	0.995934	1.36232E-03	106584.
0.879999	0.0127774	0.0107863	0	0	109059.
0.899999	0.0127009	0.0107863	0	0	111709.
0.919999	0.0126262	0.0107863	0	0	114377.
0.939999	0.0125529	0.0107863	0	0	117073.
0.959999	0.0124807	0.0107863	0	0	119806.
0.979999	0.0124090	0.0107863	0	0	122599.
1.00000	0	0	0	0	0

XLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	DTSS
3.53132	1135.30	1123.30	1096.15	1090.22	5.93774	27.1445	12.0034
3.84509	1137.19	1124.59	1096.09	1089.85	6.23462	28.5020	12.6035
4.14390	1139.10	1125.91	1096.08	1089.55	6.52588	29.8335	13.1924
4.42939	1141.03	1127.25	1096.11	1089.30	6.81274	31.1448	13.7722
4.70285	1142.96	1128.61	1096.17	1089.07	7.09692	32.4443	14.3469
4.96536	1144.90	1129.98	1096.25	1088.87	7.37891	33.7332	14.9167
5.21784	1146.85	1131.36	1096.34	1088.68	7.65967	35.0173	15.4846
5.46106	1148.80	1132.75	1096.45	1088.51	7.93970	36.2969	16.0505
5.69571	1150.76	1134.15	1096.57	1088.35	8.21899	37.5742	16.6152
5.92238	1152.73	1135.55	1096.70	1088.20	8.49829	38.8508	17.1799
6.14160	1154.71	1136.96	1096.83	1088.05	8.77808	40.1296	17.7454
6.35384	1156.69	1138.38	1096.97	1087.91	9.05786	41.4092	18.3113
6.55952	1158.68	1139.80	1097.11	1087.77	9.33862	42.6924	18.8787
6.75902	1160.68	1141.23	1097.25	1087.63	9.62012	43.9792	19.4478
6.95268	1162.69	1142.67	1097.40	1087.49	9.90259	45.2705	20.0186
7.14082	1164.70	1144.11	1097.54	1087.36	10.1860	46.5671	20.5920
7.32373	1166.73	1145.56	1097.69	1087.22	10.4712	47.8699	21.1680
7.50165	1168.76	1147.02	1097.84	1087.08	10.7576	49.1790	21.7468
7.67484	1170.81	1148.48	1097.98	1086.94	11.0449	50.4937	22.3284
7.84352	1172.85	1149.94	1098.13	1086.80	11.3330	51.8103	22.9106
8.00792	1174.90	1151.40	1098.27	1086.65	11.6216	53.1296	23.4939
8.16823	1176.94	1152.87	1098.41	1086.50	11.9109	54.4517	24.0786
8.32466	1178.99	1154.33	1098.55	1086.35	12.2007	55.7764	24.6643
8.47737	1181.05	1155.79	1098.69	1086.20	12.4912	57.1047	25.2517
8.62653	1183.10	1157.26	1098.82	1086.04	12.7822	58.4355	25.8401
8.77229	1185.16	1158.73	1098.96	1085.88	13.0740	59.7693	26.4299
8.91480	1187.21	1160.19	1099.08	1085.72	13.3665	61.1060	27.0210
9.05419	1189.27	1161.66	1099.21	1085.55	13.6594	62.4463	27.6138
9.19060	1191.33	1163.12	1099.33	1085.38	13.9536	63.7903	28.2080
9.32413	1193.39	1164.59	1099.45	1085.20	14.2483	65.1377	28.8040

XLENGTH	DTTOTAL
3.53132	45.0857
3.84509	47.3401
4.14390	49.5518
4.42939	51.7297
4.70285	53.8882
4.96536	56.0288
5.21784	58.1616
5.46106	60.2871
5.69571	62.4084
5.92238	64.5291
6.14160	66.6531
6.35384	68.7783
6.55552	70.9097
6.75902	73.0471
6.95268	75.1917
7.14082	77.3452
7.32373	79.5090
7.50165	81.6833
7.67484	83.8669
7.84352	86.0540
8.00792	88.2451
8.16823	90.4412
8.32466	92.6414
8.47737	94.8477
8.62653	97.0579
8.77229	99.2732
8.91480	101.493
9.05419	103.719
9.19060	105.952
9.32413	108.190

XLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	DTSS
9.45490	1195.46	1166.05	1099.57	1085.02	14.5437	66.4888	29.4014
9.58301	1197.52	1167.52	1099.68	1084.84	14.8401	67.8433	30.0002
9.70857	1199.59	1168.99	1099.78	1084.65	15.1375	69.2024	30.6013
9.83166	1201.66	1170.45	1099.89	1084.45	15.4355	70.5654	31.2041
9.95238	1203.73	1171.92	1099.99	1084.25	15.7346	71.9326	31.8086
10.0708	1205.80	1173.38	1100.08	1084.05	16.0347	73.3042	32.4150
10.1870	1207.87	1174.85	1100.17	1083.83	16.3354	74.6797	33.0234
10.3011	1209.95	1176.31	1100.25	1083.62	16.6375	76.0598	33.6338
10.4131	1255.07	1250.89	1241.43	1239.36	2.06958	9.46094	4.18359
11.3135	1258.48	1254.61	1245.87	1243.95	1.91357	8.74756	3.86816
12.2875	1261.99	1258.51	1250.64	1248.91	1.72290	7.87646	3.48315
13.3693	1265.65	1262.65	1255.86	1254.37	1.48511	6.78882	3.00220
14.6245	1269.54	1267.17	1261.83	1260.66	1.16870	5.34204	2.36230
16.2198	1273.94	1272.57	1269.47	1268.80	0.676758	3.09399	1.36816
18.9748	0	0	0	0	0	0	0

XLENGTH	DTTOTAL
9.45490	110.434
9.58301	112.684
9.70857	114.941
9.83166	117.205
9.95238	119.476
10.0708	121.754
10.1870	124.039
10.3011	126.331
10.4131	15.7141
11.3135	14.5293
12.2875	13.0825
13.3693	11.2761
14.6245	8.87305
16.2198	5.13892
18.9748	0

DATE 08-26-08 SNAP-8 TA-SS DOUBLE CONTAINMENT BOILER,MPP+SFHX,BODE,LO.

SFHXSH SECTION

BOUNDARY	TNAK	THG	P	LENGTH	QFLUX	U	DTNHG
1	1277.39	1072.61	271.404	18.9748	18222.4	89.9881	202.498
2	1277.52	1077.29	271.317	19.0366	17783.9	89.8416	197.947
3	1277.65	1081.98	271.228	19.0999	17346.2	89.6924	193.397
4	1277.79	1086.66	271.135	19.1647	16909.3	89.5397	188.847
5	1277.92	1091.35	271.041	19.2313	16473.1	89.3835	184.297
6	1278.06	1096.03	270.943	19.2996	16037.4	89.2230	179.745
7	1278.19	1100.72	270.842	19.3698	15602.7	89.0591	175.195
8	1278.32	1105.40	270.738	19.4419	15168.8	88.8911	170.645
9	1278.46	1110.09	270.630	19.5161	14735.9	88.7197	166.094
10	1278.59	1114.77	270.519	19.5925	14303.8	88.5440	161.544
11	1278.73	1119.45	270.404	19.6712	13872.6	88.3639	156.994
12	1278.86	1124.14	270.284	19.7523	13442.4	88.1797	152.444
13	1279.00	1128.82	270.161	19.8360	13013.2	87.9903	147.894
14	1279.13	1133.51	270.033	19.9225	12585.0	87.7960	143.344
15	1279.27	1138.19	269.900	20.0119	12157.7	87.5959	138.793
16	1279.40	1142.88	269.761	20.1045	11731.6	87.3903	134.243
17	1279.53	1147.56	269.617	20.2005	11306.4	87.1783	129.693
18	1279.67	1152.25	269.467	20.3000	10882.4	86.9598	125.143
19	1279.80	1156.93	269.311	20.4034	10459.5	86.7342	120.593
20	1279.94	1161.62	269.147	20.5110	10037.8	86.5009	116.043
21	1280.07	1166.30	268.976	20.6232	9617.35	86.2599	111.493
22	1280.21	1170.99	268.797	20.7402	9198.12	86.0099	106.943
23	1280.34	1175.67	268.608	20.8625	8780.19	85.7503	102.393
24	1280.48	1180.35	268.410	20.9907	8363.60	85.4804	97.8423
25	1280.61	1185.04	268.201	21.1253	7948.53	85.2001	93.2925
26	1280.74	1189.72	267.980	21.2669	7534.85	84.9072	88.7422
27	1280.88	1194.41	267.746	21.4163	7122.78	84.6015	84.1921
28	1281.01	1199.09	267.497	21.5743	6712.34	84.2814	79.6421
29	1281.15	1203.78	267.232	21.7420	6303.59	83.9447	75.0923
30	1281.28	1208.46	266.948	21.9205	5896.64	83.5902	70.5422

BOUNDARY	H	DTFILM	RESH	ANULIN	HLIN	ANUFOR	HFOR
1	97.2106	187.453	123888.	217.166	54.3917	252.199	64.0057
2	97.0397	183.264	123086.	216.150	54.4404	251.019	64.0630
3	96.8656	179.076	122291.	215.140	54.4896	249.846	64.1209
4	96.6875	174.887	121503.	214.137	54.5390	248.681	64.1790
5	96.5054	170.699	120722.	213.140	54.5886	247.523	64.2374
6	96.3183	166.503	119946.	212.148	54.6383	246.371	64.2959
7	96.1274	162.314	119176.	211.162	54.6882	245.227	64.3546
8	95.9317	158.118	118413.	210.182	54.7385	244.088	64.4138
9	95.7321	153.930	117657.	209.208	54.7894	242.957	64.4737
10	95.5275	149.734	116907.	208.240	54.8408	241.833	64.5342
11	95.3180	145.537	116165.	207.278	54.8927	240.716	64.5952
12	95.1036	141.345	115429.	206.322	54.9452	239.606	64.6570
13	94.8834	137.149	114700.	205.372	54.9981	238.503	64.7192
14	94.6574	132.953	113979.	204.429	55.0515	237.407	64.7822
15	94.4249	128.753	113265.	203.492	55.1054	236.319	64.8456
16	94.1861	124.557	112557.	202.562	55.1598	235.239	64.9096
17	93.9399	120.357	111857.	201.639	55.2147	234.167	64.9742
18	93.6862	116.158	111165.	200.722	55.2701	233.102	65.0393
19	93.4244	111.958	110479.	199.812	55.3259	232.045	65.1050
20	93.1537	107.754	109801.	198.909	55.3822	230.996	65.1713
21	92.8744	103.554	109130.	198.013	55.4391	229.956	65.2383
22	92.5845	99.3503	108467.	197.124	55.4964	228.924	65.3057
23	92.2838	95.1428	107810.	196.243	55.5543	227.900	65.3738
24	91.9714	90.9352	107161.	195.368	55.6126	226.885	65.4423
25	91.6469	86.7315	106520.	194.501	55.6713	225.878	65.5115
26	91.3081	82.5202	105885.	193.641	55.7306	224.879	65.5813
27	90.9547	78.3127	105258.	192.789	55.7903	223.889	65.6515
28	90.5848	74.1013	104638.	191.944	55.8505	222.908	65.7224
29	90.1959	69.8881	104025.	191.105	55.9108	221.934	65.7933
30	89.7869	65.6748	103416.	190.273	55.9713	220.967	65.8645

BOUNDARY	FVSH	FVSHLN	FVTAN
1	0.0231629	0.0123766	0.0107863
2	0.0231830	0.0123967	0.0107863
3	0.0232031	0.0124168	0.0107863
4	0.0232232	0.0124368	0.0107863
5	0.0232432	0.0124569	0.0107863
6	0.0232633	0.0124770	0.0107863
7	0.0232834	0.0124971	0.0107863
8	0.0233035	0.0125172	0.0107863
9	0.0233236	0.0125373	0.0107863
10	0.0233436	0.0125573	0.0107863
11	0.0233637	0.0125773	0.0107863
12	0.0233836	0.0125973	0.0107863
13	0.0234036	0.0126173	0.0107863
14	0.0234235	0.0126372	0.0107863
15	0.0234434	0.0126571	0.0107863
16	0.0234632	0.0126769	0.0107863
17	0.0234830	0.0126967	0.0107863
18	0.0235027	0.0127164	0.0107863
19	0.0235224	0.0127361	0.0107863
20	0.0235420	0.0127557	0.0107863
21	0.0235616	0.0127753	0.0107863
22	0.0235811	0.0127948	0.0107863
23	0.0236005	0.0128142	0.0107863
24	0.0236199	0.0128336	0.0107863
25	0.0236392	0.0128529	0.0107863
26	0.0236584	0.0128721	0.0107863
27	0.0236775	0.0128912	0.0107863
28	0.0236966	0.0129102	0.0107863
29	0.0237156	0.0129292	0.0107863
30	0.0237345	0.0129482	0.0107863

BOUNDARY	TNAK	THG	P	LENGTH	QFLUX	U	DTNHG
31	1281.42	1213.15	266.644	22.1114	5491.56	83.2157	65.9919
32	1281.55	1217.83	266.315	22.3163	5088.58	82.8191	61.4421
33	1281.69	1222.52	265.959	22.5375	4687.78	82.3974	56.8923
34	1281.82	1227.20	265.570	22.7776	4289.29	81.9473	52.3420
35	1281.96	1231.88	265.143	23.0400	3893.38	81.4646	47.7922
36	1282.09	1236.57	264.670	23.3291	3500.19	80.9439	43.2422
37	1282.22	1241.25	264.142	23.6507	3110.03	80.3784	38.6924
38	1282.36	1245.94	263.543	24.0126	2723.12	79.7585	34.1421
39	1282.49	1250.62	262.856	24.4259	2339.93	79.0717	29.5925
40	1282.63	1255.31	262.052	24.9070	1960.82	78.2998	25.0425
41	1282.76	1259.99	261.085	25.4810	0	0	0

BOUNDARY	H	DTFILM	RESH	ANULIN	HLIN	ANUFOR	HFOR
31	89.3549	61.4578	102814.	189.447	56.0319	220.008	65.9358
32	88.8978	57.2407	102217.	188.627	56.0927	219.056	66.0074
33	88.4121	53.0217	101627.	187.813	56.1538	218.111	66.0793
34	87.8941	48.8009	101042.	187.006	56.2152	217.173	66.1516
35	87.3391	44.5781	100462.	186.204	56.2770	216.242	66.2243
36	86.7408	40.3524	99889.1	185.408	56.3392	215.318	66.2975
37	86.0917	36.1249	99321.6	184.619	56.4019	214.401	66.3712
38	85.3809	31.8935	98760.0	183.835	56.4651	213.491	66.4456
39	84.5945	27.6602	98204.4	183.057	56.5289	212.588	66.5207
40	83.7115	23.4236	97654.7	182.285	56.5932	211.691	66.5964
41	0	0	0	0	0	0	0

BOUNDARY	FVSH	FVSHLN	FVTAN
31	0.0237534	0.0129671	0.0107863
32	0.0237723	0.0129860	0.0107863
33	0.0237912	0.0130048	0.0107863
34	0.0238099	0.0130236	0.0107863
35	0.0238287	0.0130424	0.0107863
36	0.0238474	0.0130610	0.0107863
37	0.0238660	0.0130796	0.0107863
38	0.0238845	0.0130982	0.0107863
39	0.0239030	0.0131167	0.0107863
40	0.0239214	0.0131351	0.0107863
41	0	0	0

SHLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	DTSS
18.9748	1273.30	1270.40	1263.84	1262.40	1.43457	6.55811	2.90015
19.0366	1273.53	1270.70	1264.30	1262.90	1.40015	6.40039	2.83032
19.0999	1273.76	1271.00	1264.76	1263.40	1.36572	6.24268	2.76050
19.1647	1274.00	1271.31	1265.22	1263.89	1.33130	6.08545	2.69116
19.2313	1274.23	1271.61	1265.68	1264.39	1.29687	5.92847	2.62158
19.2996	1274.46	1271.91	1266.14	1264.88	1.26270	5.77173	2.55225
19.3698	1274.70	1272.21	1266.60	1265.37	1.22827	5.61523	2.48315
19.4419	1274.93	1272.52	1267.06	1265.86	1.19409	5.45923	2.41406
19.5161	1275.16	1272.82	1267.52	1266.36	1.16016	5.30322	2.34521
19.5925	1275.40	1273.12	1267.97	1266.85	1.12622	5.14771	2.27637
19.6712	1275.63	1273.42	1268.43	1267.34	1.09229	4.99268	2.20776
19.7523	1275.86	1273.72	1268.88	1267.83	1.05835	4.83789	2.13940
19.8360	1276.09	1274.02	1269.34	1268.32	1.02441	4.68335	2.07104
19.9225	1276.33	1274.32	1269.79	1268.80	0.990723	4.52930	2.00293
20.0119	1276.56	1274.62	1270.25	1269.29	0.957275	4.37549	1.93481
20.1045	1276.79	1274.92	1270.70	1269.78	0.923584	4.22217	1.86719
20.2005	1277.02	1275.22	1271.15	1270.26	0.890137	4.06909	1.79932
20.3000	1277.25	1275.52	1271.60	1270.75	0.856689	3.91650	1.73193
20.4034	1277.48	1275.82	1272.05	1271.23	0.823486	3.76440	1.66455
20.5110	1277.71	1276.12	1272.50	1271.71	0.790283	3.61255	1.59741
20.6232	1277.94	1276.41	1272.95	1272.19	0.757080	3.46118	1.53052
20.7402	1278.17	1276.71	1273.40	1272.68	0.724121	3.31030	1.46387
20.8625	1278.40	1277.01	1273.85	1273.15	0.691406	3.15991	1.39746
20.9907	1278.63	1277.30	1274.29	1273.63	0.658447	3.01001	1.33105
21.1253	1278.86	1277.60	1274.74	1274.11	0.625732	2.86060	1.26514
21.2669	1279.09	1277.89	1275.18	1274.59	0.593262	2.71167	1.19922
21.4163	1279.32	1278.19	1275.62	1275.06	0.560791	2.56348	1.13354
21.5743	1279.55	1278.48	1276.06	1275.53	0.528564	2.41577	1.06836
21.7420	1279.78	1278.77	1276.50	1276.01	0.496338	2.26880	1.00317
21.9205	1280.00	1279.06	1276.94	1276.48	0.464355	2.12231	0.938477

SHLENGTH	CTTOTAL
18.9748	10.8928
19.0366	10.6309
19.0999	10.3689
19.1647	10.1079
19.2313	9.84692
19.2996	9.58667
19.3698	9.32666
19.4419	9.06738
19.5161	8.80859
19.5925	8.55029
19.6712	8.29272
19.7523	8.03564
19.8360	7.77881
19.9225	7.52295
20.0119	7.26758
20.1045	7.01294
20.2005	6.75854
20.3000	6.50513
20.4034	6.25244
20.5110	6.00024
20.6232	5.74878
20.7402	5.49829
20.8625	5.24878
20.9907	4.99951
21.1253	4.75146
21.2669	4.50415
21.4163	4.25781
21.5743	4.01270
21.7420	3.76831
21.9205	3.52515

SHLENGTH	T4	T3	T2	T1	DTTA	DTSTAG	DTSS
22.1114	1280.23	1279.35	1277.38	1276.95	0.432373	1.97632	0.874023
22.3163	1280.46	1279.65	1277.81	1277.41	0.400635	1.83130	0.809814
22.5375	1280.68	1279.94	1278.25	1277.88	0.369141	1.68726	0.746094
22.7776	1280.91	1280.22	1278.68	1278.34	0.337646	1.54370	0.682617
23.0400	1281.13	1280.51	1279.11	1278.80	0.306641	1.40137	0.619629
23.3291	1281.36	1280.80	1279.54	1279.26	0.275635	1.25977	0.557129
23.6507	1281.58	1281.08	1279.97	1279.72	0.244873	1.11938	0.495117
24.0126	1281.80	1281.37	1280.39	1280.17	0.214355	0.980225	0.433350
24.4259	1282.02	1281.65	1280.81	1280.62	0.184326	0.842285	0.372559
24.9070	1282.25	1281.93	1281.23	1281.07	0.154541	0.705811	0.312256
25.4810	0	0	0	0	0	0	0

SHLENGTH	CTTOTAL
22.1114	3.28271
22.3163	3.04175
22.5375	2.80249
22.7776	2.56396
23.0400	2.32764
23.3291	2.09253
23.6507	1.85937
24.0126	1.62793
24.4259	1.39917
24.9070	1.17261
25.4810	0

SNAP-8 BODEPE COMPUTER PROGRAM - BOILER DESIGN AND PERFORMANCE ANALYSIS OUTPUT 6

DATE C8-26-08 SNAP-8 TA-SS DOUBLE CONTAINMENT BOILER,MPP+SFHX,BODE,LO.

INPUT DATA

WH	=	11800.000	TNBO	=	1110.000	TSS	=	0.035
PHBO	=	260.000	QHL	=	12.000	HNF	=	3000.000
THBI	=	500.000	D1	=	0.670	AKNT	=	13.000
THBO	=	1260.000	TTA	=	0.040	AKST	=	15.000
TNBI	=	1280.000	TNAK	=	0.080	AKHT	=	40.000
DPHITR	=	1.000	PTRLO	=	250.000	AN2	=	16.000
DPLOTR	=	0.010	PMPP	=	6.000	XL	=	41.000
CONV	=	0.010	DMPP	=	0.080	DX	=	0.020
CNT	=	25.000	HMPP	=	0.032	DELMPP	=	0.0
PTRHI	=	400.000	AN1	=	7.000	FXINT	=	0.500
CONXP	=	1.000	FINTX	=	0.050	DELTCT	=	0.0
DBAR	=	0.188	CONX	=	3.000	ITABLE	=	1
PHELIX	=	3.000	DROPNO	=	10.000	JTABLE	=	1
THICK	=	0.030	X0	=	0.100	IGEOM	=	1
XWET	=	0.880	XI	=	41.000	PITCH1	=	0.0
DRAR1	=	0.0						
THICK1	=	0.0						
C1	=	1.000						
C2	=	1.000						
WNTOTT	=	0.0						

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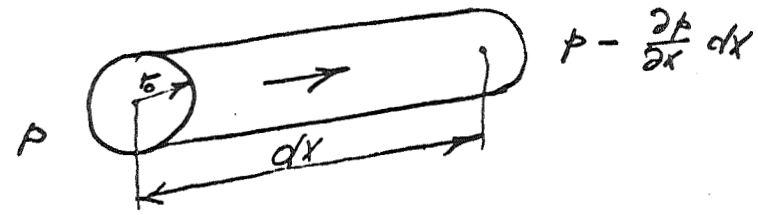
C-1 WETTED TWO-PHASE FLOW MODEL IN BARE TUBE

Wetted two-phase flow model in a bare tube consists of gas (vapor) core and annular liquid film at the tube wall. Both the gas (vapor) core and the annular liquid film are of concentric geometry. Laminar and turbulent flow patterns are postulated for the liquid film and gas (vapor) core respectively. Such a model represents separated two-phase flow regime in once through flow boilers when the working fluid wets the tube wall and annular liquid film exists at the wall. Basic heat and momentum transfer correlations for separated two-phase flow regime were developed for bare tube model and then modified and applied to helical flow passage geometry.

C-2 BASIC CORRELATIONS FOR WETTED TWO PHASE FLOW MODEL IN BARE TUBE

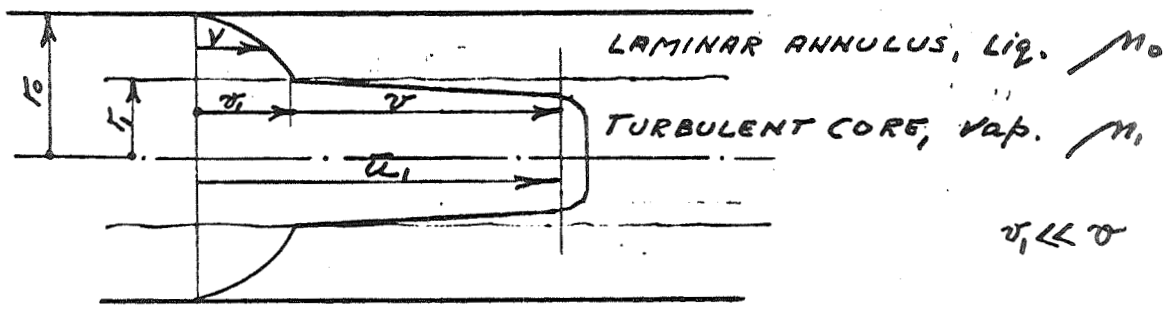
Shear relation for single phase flow in bare tube:



$$p \pi r^2 - \left(p - \frac{\partial p}{\partial x} dx\right) \pi r^2 = 2\pi r \, dx \, \tau$$

$$\therefore \quad \tau = \frac{\partial p}{\partial x} \frac{r}{2} \qquad \text{holds for } 0 < r < r_o$$

Velocity profile in separated two phase flow regime:



Laminar flow velocity profile: for $r_1 < r < r_o$:

$$\tau = -\mu_o \frac{dv}{dr} = \frac{\partial p}{\partial x} \frac{r}{2}$$

$$\int_0^v dv = -\frac{1}{2\mu_o} \frac{\partial p}{\partial x} \int_{r_o}^{r} r \, dr$$

$$v = -\frac{1}{4\mu_o} \frac{\partial p}{\partial x} \left(r^2 - r_o^2\right) \quad \leftarrow \text{Velocity profile} \qquad \text{Eq. 1}$$

$$v_1 = -\frac{1}{4\mu_o} \frac{\partial p}{\partial x} \left(r_1^2 - r_o^2\right) \quad \leftarrow \text{Interface velocity} \qquad \text{Eq. 2}$$

Average velocity for laminar annular flow:

$$V_o = V_o \pi (r_o^2 - r_1^2) = \int^A v\, dA = \int_{r_1}^{r_o} v\, 2\pi r\, dr$$

$$V_o = \frac{2}{r_o^2 - r_1^2} \int_{r_1}^{r_o} v\, r\, dr$$

$$= \frac{2}{r_o^2 - r_1^2} \int_{r_1}^{r_o} -\frac{1}{4\mu_o} \frac{\partial p}{\partial x} (r^2 - r_o^2)\, r\, dr$$

$$= -\frac{1}{r_o^2 - r_1^2} \frac{1}{2\mu_o} \frac{\partial p}{\partial x} \int_{r_1}^{r_o} (r^2 - r_o^2)\, r\, dr$$

$$= -\frac{1}{r_o^2 - r_1^2} \frac{1}{2\mu_o} \frac{\partial p}{\partial x} \left[\frac{r^4}{4} - r_o^2 \left(\frac{r^2}{2} \right) \right]_{r_1}^{r_o}$$

$$= \boxed{\frac{1}{r_o^2 - r_1^2} \frac{1}{2\mu_o} \frac{\partial p}{\partial x} \left[-\left(\frac{r_o^4}{4} - \frac{r_1^4}{4} \right) + r_o^2 \left(\frac{r_o^2}{2} - \frac{r_1^2}{2} \right) \right]} \qquad \text{Eq. 3}$$

$$= \boxed{-\frac{1}{8\mu_o} \frac{\partial p}{\partial x} (r_o^2 - r_1^2)} \qquad \text{Eq. 3a.}$$

Weight flow for laminar annulus:

$$W_o = V_o \rho_o \pi (r_o^2 - r_1^2)$$

$$= \pi \rho_o \cancel{(r_o^2 - r_1^2)} \frac{1}{\cancel{(r_o^2 - r_1^2)}} \frac{1}{2\mu_o} \frac{\partial p}{\partial x} \left[-\left(\frac{r_o^4}{4} - \frac{r_1^4}{4} \right) + r_o^2 \left(\frac{r_o^2}{2} - \frac{r_1^2}{2} \right) \right]$$

$$= \boxed{\frac{\pi \rho_o}{4\mu_o} \left[-\frac{1}{2} (r_o^4 - r_1^4) + r_o^2 (r_o^2 - r_1^2) \right] \frac{\partial p}{\partial x}} \qquad \text{Eq. 4}$$

$$= -\frac{1}{8\mu_o} \frac{\partial p}{\partial x} (r_o^2 - r_1^2)\, \rho_o \pi (r_o^2 - r_1^2)$$

$$= \boxed{-\frac{\pi \rho_o}{8\mu_o} (r_o^2 - r_1^2)^2 \frac{\partial p}{\partial x}} \qquad \text{Eq. 4a.}$$

Pressure gradient in laminar annulus:

$$\left(\frac{\partial p}{\partial x}\right)_0 = \frac{W_0}{\frac{\pi \rho_0}{4\mu_0}\left[-\frac{1}{2}\left(r_0^4 - r_1^4\right) + r_0^2\left(r_0^2 - r_1^2\right)\right]}$$

$$= \frac{W_0}{\frac{\pi \rho_0 r_0^4}{4\mu_0}\left[-\frac{1}{2}\left(1-\rho^4\right) + \left(1-\rho^2\right)\right]}$$

or

$$= -\frac{W_0}{\frac{\pi \rho_0}{8\mu_0}\left(r_0^2 - r_1^2\right)^2} \qquad \text{Eq. 5}$$

$$= -\frac{W_0}{\frac{\pi \rho_0 r_0^4}{8\mu_0}\left(1-\rho^2\right)^2} \qquad \text{Eq. 5a.}$$

where

$$\rho = \frac{r_1}{r_0}$$

Pressure gradient for turbulent gas (vapor) core at

$0 < r < r_1$:

$$\left(\frac{\partial p}{\partial x}\right)_1 = \xi_{int} \frac{\rho_1}{2r_1} \frac{v^2}{2g_c} \qquad \text{Eq. 6}$$

where v is gas (vapor) core velocity relative to the liquid gas interface.

The average absolute velocity of the gas (vapor) core is:

$$\bar{u}_1 = v_1 + v$$

where v_1 is the liq.-gas interface velocity.

Thus the gas core weight flow is:

$$W_1 = V_1 \rho_1 = \bar{u}_1 A_1 \rho_1 = \bar{u}_1 \pi r_1^2 \rho_1 = \pi r_1^2 \rho_1 (v_1 + v)$$

$$= \pi r_1^2 \rho_1 \left[-\frac{1}{4\mu_0} \left(\frac{\partial p}{\partial x}\right)_1 (r_1^2 - r_0^2) + v \right] \qquad \text{Eq. 7}$$

From above follows:

$$v = \frac{W_1}{\pi r_1^2 \rho_1} + \frac{1}{4\mu_0} (r_1^2 - r_0^2) \left(\frac{\partial p}{\partial x}\right)_1$$

$$v^2 = \frac{W_1^2}{\pi^2 r_1^4 \rho_1^2} + \frac{1}{2\mu_0} (r_1^2 - r_0^2) \left(\frac{\partial p}{\partial x}\right)_1 \frac{W_1}{\pi r_1^2 \rho_1} + \frac{1}{16\mu_0^2} (r_1^2 - r_0^2)^2 \left(\frac{\partial p}{\partial x}\right)_1^2$$

$$= \frac{W_1^2}{\pi^2 r_1^4 \rho_1^2} - \frac{1}{2\mu_0} (r_0^2 - r_1^2) \left(\frac{\partial p}{\partial x}\right)_1 \frac{W_1}{\pi r_1^2 \rho_1} + \frac{1}{16\mu_0^2} (r_0^2 - r_1^2)^2 \left(\frac{\partial p}{\partial x}\right)_1^2 \qquad \text{Eq. 8}$$

The substitution of Eq. 8 into Eq. 6 results in:

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\xi_{int}\,\rho_1}{4 r_1 g_c}\left[\frac{W_1^2}{\pi^2 r_1^4 \rho_1^2} - \frac{1}{2\mu_0}(r_0^2 - r_1^2)\frac{W_1}{\pi r_1^2 \rho_1}\left(\frac{\partial p}{\partial x}\right)_1 + \frac{1}{16\mu_0^2}(r_0^2 - r_1^2)^2\left(\frac{\partial p}{\partial x}\right)_1^2\right]$$

$$= \frac{\xi_{int}}{4\pi^2 r_1^5 \rho_1 g_c}\left[W_1^2 - \frac{1}{2\mu_0}(r_0^2 - r_1^2)\,\pi r_1^2 \rho_1 W_1\left(\frac{\partial p}{\partial x}\right)_1 + \frac{1}{16\mu_0^2}(r_0^2 - r_1^2)^2 \pi^2 r_1^4 \rho_1^2\left(\frac{\partial p}{\partial x}\right)_1^2\right]$$

Eq. 9

In separated two phase flow regime $\left(\frac{\partial p}{\partial x}\right)_0 = \left(\frac{\partial p}{\partial x}\right)_1$. Therefore, the $\left(\frac{\partial p}{\partial x}\right)_1$ in the right side of Eq. 9 can be substituted by Eq. 5 to yield the solution for two phase pressure drop. Consequently

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\xi_{int}}{4\pi^2 r_1^5 \rho_1 g_c}\left[W_1^2 - \frac{1}{\cancel{2}\cancel{\mu_0}}\cancel{(r_0^2 - r_1^2)}\,\cancel{\pi} r_1^2 \rho_1 W_1 \frac{\overset{4}{\cancel{2}}\cancel{\mu_0} W_0}{\cancel{\pi}\rho_0 (r_0^2 - r_1^2)^{\cancel{2}}} + \frac{1}{\cancel{16}\cancel{\mu_0^2}}\cancel{(r_0^2 - r_1^2)^2}\,\cancel{\pi^2} r_1^4 \rho_1^2 \frac{\overset{4}{\cancel{16}}\cancel{\mu_0^2} W_0^2}{\cancel{\pi^2}\rho_0^2 (r_0^2 - r_1^2)^{\cancel{2}}}\right]$$

$$= \frac{\xi_{int}}{4\pi^2 r_1^5 \rho_1 g_c}\left[W_1^2 - \frac{4 r_1^2}{r_0^2 - r_1^2}\frac{\rho_1}{\rho_0} W_0 W_1 + \frac{4 r_1^4}{(r_0^2 - r_1^2)^2}\left(\frac{\rho_1}{\rho_0}\right)^2 W_0^2\right]$$

Eq. 10

Pressure drop gradient for gas phase alone:

$$\left(\frac{\partial p}{\partial x}\right)_{GP} = \frac{\xi_{tube}}{4\pi^2 r_0^5 \rho_1 g_c} W_1^2$$

Eq. 11

Denoting the two phase pressure drop gradient by

$$\left(\frac{\partial p}{\partial x}\right)_{TP} = \left(\frac{\partial p}{\partial x}\right)_1$$

the two phase pressure drop factor is defined as follows:

$$\phi = \frac{\left(\frac{\partial p}{\partial x}\right)_{TP}}{\left(\frac{\partial p}{\partial x}\right)_{GP}} = \frac{\xi_{int}}{\xi_{tube}} \left(\frac{r_0}{r_1}\right)^5 \left[1 - \frac{4r_1^2}{r_0^2 - r_1^2} \frac{\rho_1}{\rho_0} \frac{W_0}{W_1} + \frac{4r_1^4}{(r_0^2 - r_1^2)^2} \left(\frac{\rho_1}{\rho_0}\right)^2 \left(\frac{W_0}{W_1}\right)^2\right]$$

$$= \frac{\xi_{int}}{\xi_{tube}} \left(\frac{r_0}{r_1}\right)^5 \left[1 - 2 \frac{2r_1^2}{r_0^2 - r_1^2} \frac{\rho_1}{\rho_0} \frac{W_0}{W_1} + \left(\frac{2r_1^2}{r_0^2 - r_1^2} \frac{\rho_1}{\rho_0} \frac{W_0}{W_1}\right)^2\right]$$

$$= \frac{\xi_{int}}{\xi_{tube}} \left(\frac{r_0}{r_1}\right)^5 \left[1 - \left(\frac{2r_1^2}{r_0^2 - r_1^2} \frac{\rho_1}{\rho_0} \frac{W_0}{W_1}\right)\right]^2 \qquad \text{Eq. 11}$$

Introducing

$$W_0 = (1 - \bar{X})\, W_{TOT}$$

$$W_1 = \bar{X}\, W_{TOT}$$

the two phase pressure drop factor becomes:

$$\phi = \frac{\xi_{int}}{\xi_{tube}} \left(\frac{r_0}{r_1}\right)^5 \left[1 - \left(\frac{2r_1^2}{r_0^2 - r_1^2}\right)\left(\frac{\rho_1}{\rho_0}\right)\left(\frac{1 - \bar{X}}{\bar{X}}\right)\right]^2 \qquad \text{Eq. 12.}$$

NOTE: The BODEPE computer code uses

$$-\frac{2r_1^2}{r_0^2 - r_1^2} = +\frac{(r_1^2 - r_0^2)\, r_1^2}{\left[-\frac{1}{2}(r_0^4 - r_1^4) + r_0^2 (r_0^2 - r_1^2)\right]}$$

which is identical expression.

Solution for liquid film thickness is obtained from Eq. 5 and 9 noting that

$$\left(\frac{\partial p}{\partial x}\right)_0 = \left(\frac{\partial p}{\partial x}\right)_1$$

The rearrangement of Eq. 9 provides

$$\frac{4 r_1^5 \pi^2 \rho_1 g_c}{\xi_{int}}\left(\frac{\partial p}{\partial x}\right)_1 = W_1^2 - \frac{1}{2\mu_0}(r_0^2 - r_1^2)\pi r_1^2 \rho_1 W_1\left(\frac{\partial p}{\partial x}\right)_1 +$$

$$+ \frac{1}{16\mu_0^2}(r_0^2 - r_1^2)^2 \pi^2 r_1^4 \rho_1^2 \left(\frac{\partial p}{\partial x}\right)_1^2$$

$$\therefore \frac{1}{16\mu_0^2}(r_0^2 - r_1^2)^2 \pi^2 r_1^4 \rho_1^2 \left(\frac{\partial p}{\partial x}\right)_1^2 - \left[\frac{1}{2\mu_0}(r_0^2 - r_1^2)\pi r_1^2 \rho_1 W_1 + \frac{4 r_1^5 \pi^2 \rho_1 g_c}{\xi_{int}}\right]\left(\frac{\partial p}{\partial x}\right)_1 +$$

$$+ W_1^2 = 0.$$

$$\therefore \frac{\xi_{int}(r_0^2 - r_1^2)^2 \cancel{\pi^2} \cancel{r_1^4} \rho_1^{\cancel{2}}}{16\mu_0^2 \; 4 r_1^{\cancel{5}} \cancel{\pi^2} \cancel{\rho_1} g_c}\left(\frac{\partial p}{\partial x}\right)_1^2 - \left[\frac{\xi_{int}(r_0^2 - r_1^2)\cancel{\pi} \cancel{r_1^2} \cancel{\rho_1} W_1}{2\mu_0 \; 4 r_1^{\cancel{3}} \cancel{\pi^2} \cancel{\rho_1} g_c} + 1\right]\left(\frac{\partial p}{\partial x}\right)_1 +$$

$$+ \frac{\xi_{int}}{4 r_1^5 \pi^2 \rho_1 g_c} W_1^2 = 0.$$

$$\therefore \overbrace{\left[\frac{\xi_{int}\rho_1}{64 r_1 g_c}\frac{(r_0^2 - r_1^2)^2}{\mu_0^2}\right]}^{A}\left(\frac{\partial p}{\partial x}\right)_1^2 - \overbrace{\left[\frac{\xi_{int}}{8 r_1 g_c}\frac{r_0^2 - r_1^2}{\mu_0}\frac{W_1}{\pi r_1^2} + 1\right]}^{B}\left(\frac{\partial p}{\partial x}\right)_1 +$$

$$+ \overbrace{\left[\frac{\xi_{int}}{4\pi g_c}\frac{W_1^2}{\pi^2 r_1^4 \rho_1}\right]}^{C} = 0.$$

$$\therefore A\left(\frac{\partial p}{\partial x}\right)_1^2 - B\left(\frac{\partial p}{\partial x}\right)_1 + C = 0.$$

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{B + \sqrt{B^2 - 4AC}}{2A}$$

$$A = \frac{\xi_{int}\,\rho_1}{64\,g_c\,\mu_0^2}\;\frac{r_0^{\cancel{3}}\left(\frac{r_0^2-r_1^2}{r_0^2}\right)^2}{\cancel{r_0}\left(\frac{r_1}{r_0}\right)} = \frac{\xi_{int}\,\rho_1}{64\,g_c\,\mu_0^2}\;r_0^3\;\frac{(1-\rho^2)^2}{\rho}$$

$$B = -\left[\frac{\xi_{int}\,W_1}{8\pi\,g_c\,\mu_0}\cdot\frac{\cancel{r_0^2}\,\frac{r_0^2-r_1^2}{r_0^2}}{\cancel{r_0^2}\,\frac{r_1^3}{r_0^3}} + 1\right] = -\left[\frac{\xi_{int}\,W_1}{8\pi\,g_c\,\mu_0}\;\frac{1-\rho^2}{r_0\,\rho^3} + 1\right]$$

$$C = \frac{\xi_{int}\,W_1^2}{4\pi^2 g_c\,\rho_1}\;\frac{1}{r_0^5\,\frac{r_1^5}{r_0^5}} = \frac{\xi_{int}\,W_1^2}{4\pi^2 g_c\,\rho_1}\;\frac{1}{r_0^5\,\rho^5}$$

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\left[\frac{\xi_{int}\,W_1}{8\pi\,g_c\,r_0\,\mu_0}\;\frac{1-\rho^2}{\rho^3}+1\right] + \sqrt{\left[\frac{\xi_{int}\,W_1}{8\pi\,g_c\,r_0\,\mu_0}\;\frac{1-\rho^2}{\rho^3}+1\right]^2 - \cancel{4}\left[\frac{\xi_{int}\,\rho_1\,r_0^{\cancel{3}}}{64\,g_c\,\mu_0^2}\,\frac{(1-\rho^2)^2}{\rho}\;\frac{\xi_{int}\,W_1^2}{\cancel{4}\pi^2 g_c\,r_0^5\,\cancel{4}}\;\frac{1}{\rho^5}\right]}}{2\;\frac{\xi_{int}\,\rho_1\,r_0^3}{64\,g_c\,\mu_0^2}\cdot\frac{(1-\rho^2)^2}{\rho}}$$

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\left[\frac{\xi_{int}\,W_1}{8\pi\,g_c\,r_0\,\mu_0}\;\frac{1-\rho^2}{\rho^3}+1\right] + \sqrt{\left[\frac{\xi_{int}\,W_1}{8\pi\,g_c\,r_0\,\mu_0}\;\frac{1-\rho^2}{\rho^3}+1\right]^2 - \left[\frac{\xi_{int}^2\,W_1^2}{64\pi^2 g_c^2\,r_0^2\,\mu_0^2}\left(\frac{1-\rho^2}{\rho^3}\right)^2\right]}}{\frac{\xi_{int}\,\rho_1\,r_0^3}{32\,g_c\,\mu_0^2}\;\frac{(1-\rho^2)^2}{\rho}}$$

Noting that in parallel network

$$\left(\frac{\partial p}{\partial x}\right)_1 = \left(\frac{\partial p}{\partial x}\right)_0$$

the solution for ρ is:

$$\frac{\left[\frac{\xi_{int} W_1}{8\pi g_c r_0 \mu_0}\frac{1-\rho^2}{\rho^3}+1\right]+\sqrt{\left[\frac{\xi_{int} W_1}{8\pi g_c r_0 \mu_0}\frac{1-\rho^2}{\rho^3}+1\right]^2-\left[\frac{\xi_{int}^2 W_1^2}{64\pi^2 g_c^2 r_0^2 \mu_0^2}\left(\frac{1-\rho^2}{\rho^3}\right)^2\right]}}{\frac{\xi_{int} \rho_1 r_0^3}{32\, g_c \mu_0^2}\frac{(1-\rho^2)^2}{\rho}} = \frac{\frac{8\mu_0}{\pi r_0^2 \rho_0} W_0}{(1-\rho^2)^2}$$

$$\frac{\left[\frac{\xi_{int} W_1}{8\pi g_c r_0 \mu_0}\frac{1-\rho^2}{\rho^3}+1\right]+\sqrt{2\left[\frac{\xi_{int} W_1}{8\pi g_c r_0 \mu_0}\frac{1-\rho^2}{\rho^3}\right]+1}}{\frac{\xi_{int} \rho_1 \cancel{r_0^3}}{\frac{\cancel{32}}{4} g_c \mu_0^{\cancel{2}}}\frac{\cancel{8\mu_0} W_0}{\pi r_0^{\cancel{2}} \rho_0}} = \frac{1}{\rho}$$

$$\frac{\left[\frac{\cancel{\xi_{int}} W_1}{\cancel{8\pi} g_c \cancel{r_0} \cancel{\mu_0}}\frac{(1-\rho^2)\cancel{\pi} \cancel{r_0} \rho_0 \cancel{4} g_c \cancel{\mu_0}}{\rho^3 \cancel{\xi_{int}} \rho_1 W_0}+\frac{4 g_c \mu_0 \pi r_0 \rho_0}{\xi_{int} \rho_1 W_0}\right]}{2} + \sqrt{2\left[\frac{\frac{\cancel{\xi_{int}}}{8\cancel{\pi}}\frac{W_1}{\cancel{g_c r_0 \mu_0}}\frac{1-\rho^2}{\rho^3}}{\frac{\xi_{int}}{16\pi}\frac{W_0^2}{(g_c r_0 \mu_0)^2}\left(\frac{\rho_1}{\rho_0}\right)^2}\right]+\frac{16\pi^2}{\xi_{int}^2}\frac{(g_c r_0 \mu_0)^2}{W_0^2}\left(\frac{\rho_0}{\rho_1}\right)^2} = \frac{-1}{\rho}$$

$$\left[\frac{1}{2}\left(\frac{W_1}{W_0}\right)\left(\frac{\rho_0}{\rho_1}\right)\left(\frac{1-\rho^2}{\rho^3}\right)+\left(\frac{4\pi}{\xi_{int}}\right)\left(\frac{g_c r_0 \mu_0}{W_0}\right)\left(\frac{\rho_0}{\rho_1}\right)\right]+\sqrt{\left(\frac{4\pi}{\xi_{int}}\right)\left(\frac{W_1}{W_0}\right)\left(\frac{g_c r_0 \mu_0}{W_0}\right)\left(\frac{\rho_0}{\rho_1}\right)^2\left(\frac{1-\rho^2}{\rho^3}\right)+\left(\frac{4\pi}{\xi_{int}}\frac{g_c r_0 \mu_0}{W_0}\frac{\rho_0}{\rho_1}\right)^2} = \frac{1}{\rho}$$

$$\frac{W_1}{W_0}\frac{\rho_0}{\rho_1} = \frac{W_1 \rho_0 \mu_1}{W_0 \rho_1 \mu_0}\frac{\mu_0}{\mu_1} = \mathcal{X}\frac{\mu_0}{\mu_1}$$

$$\frac{g_c r_0 \mu_0}{W_0}\frac{\rho_0}{\rho_1} = \frac{g_c r_0 \mu_1}{W_1}\frac{W_1 \rho_0 \mu_0}{W_0 \rho_1 \mu_1} = \frac{g_c r_0 \mu_1}{W_1 \mu_0}\frac{W_1 \rho_0 \mu_1}{W_0 \rho_1 \mu_0}\left(\frac{\mu_0}{\mu_1}\right)^2 = \mathcal{Y}\mathcal{X}\left(\frac{\mu_0}{\mu_1}\right)^2$$

$$\frac{W_1}{W_0}\,\frac{g_c r_0 \mu_0}{W_0}\left(\frac{\rho_0}{\rho_1}\right)^2 = \frac{W_1 \rho_0}{W_0 \rho_1}\,\frac{g_c r_0 \mu_0}{W_0}\,\frac{\rho_0}{\rho_1} = \mathcal{X}\frac{\mu_0}{\mu_1}\; \mathcal{Y}\mathcal{X}\left(\frac{\mu_0}{\mu_1}\right)^2 = \mathcal{X}^2\mathcal{Y}\left(\frac{\mu_0}{\mu_1}\right)^3$$

$$\mathcal{X} = \frac{W_1 \rho_0 \mu_1}{W_0 \rho_1 \mu_0} = \frac{\bar{X}\,\rho_0 \mu_1}{(1-\bar{X})\,\rho_1 \mu_0} \qquad 12a$$

$$\mathcal{Y} = \frac{g_c r_0 \mu_1}{W_1}$$

where $g_c = 32.2 \ \frac{lbm\text{-}ft}{lbf\text{-}sec^2}$

$r_0 = ft$

$\mu_1 = \frac{lbf\text{-}sec}{ft^2}$

$W_1 = lbm/sec$

$$\mathcal{Y} = \frac{11 r_0 \mu_1}{12 \bar{X} W_{TOT}}$$

where $r_0 = in.$ 12b

$\mu_1 = \frac{lbm}{hr\text{-}ft}$

$W_{TOT} = lbm/hr$ – total flow

THE final form is:

$$\left[\frac{1}{2}\mathcal{X}\left(\frac{\mu_0}{\mu_1}\right)\left(\frac{1-\rho^2}{\rho^3}\right) + \left(\frac{4\pi}{\xi_{in}^2}\right)\mathcal{X}\mathcal{Y}\left(\frac{\mu_0}{\mu_1}\right)^2\right] + \sqrt{\left(\frac{4\pi}{\xi_{in}^2}\right)\mathcal{X}^2\mathcal{Y}\left(\frac{\mu_0}{\mu_1}\right)^3\left(\frac{1-\rho^2}{\rho^3}\right) + \left(\frac{4\pi}{\xi_{in}^2}\right)^2\mathcal{X}^2\mathcal{Y}^2\left(\frac{\mu_0}{\mu_1}\right)^4} = \frac{1}{\rho}$$

$\frac{4}{4}$ $\frac{6}{4}$

Eq. 13

NOTE: The BODEPG computer code uses the following form of Eq. 13:

$$-\left[\mathcal{X}\left(\frac{\mu_0}{\mu_1}\right)\left(\frac{\rho^2-1}{\rho^3}\right)-\frac{8\pi}{\xi_{inj}}\mathcal{X}\mathcal{Y}\left(\frac{\mu_0}{\mu_1}\right)^2\right]+$$

$$+\sqrt{-2\left[\frac{8\pi}{\xi_{inj}}\mathcal{X}^2\mathcal{Y}\left(\frac{\mu_0}{\mu_1}\right)^3\left(\frac{\rho^2-1}{\rho^3}\right)+\left(\frac{8\pi}{\xi_{inj}}\right)^2\mathcal{X}^2\mathcal{Y}^2\left(\frac{\mu_0}{\mu_1}\right)^4\right.}=\frac{2}{\rho}$$

which is identical correlation. The coding notation for this equation is:

$XX(NN) = \mathcal{X}$

$YY(NN) = \mathcal{Y}$

$AMUXF = \mu_0$

$AMUXV = \mu_1$

$FXINT = \xi_{inj}$

$3.14159 = \pi$

$R\phi X(NN) = \rho$.

C-3 WETTED TWO PHASE FLOW MODEL IN MPP.

geometry:

$$X_c = \frac{d+\ell}{\cos\alpha}$$

$$2\pi r_0 = N_2 X_c = N_2 \frac{d+\ell}{\cos\alpha}$$

$$\alpha = \arctan \frac{\pi D}{p}$$

$$p = 6''$$

$$d = \frac{2\pi r_0}{N_2}\cos\alpha - \ell$$

$$X_c = d_c + \ell_c$$

$$d_c = \frac{d}{\cos\alpha}$$

$$\ell_c = \frac{\ell}{\cos\alpha}.$$

$$\beta = \frac{d_c}{r_0} = \frac{d}{r_0\cos\alpha} \quad \text{radians}$$

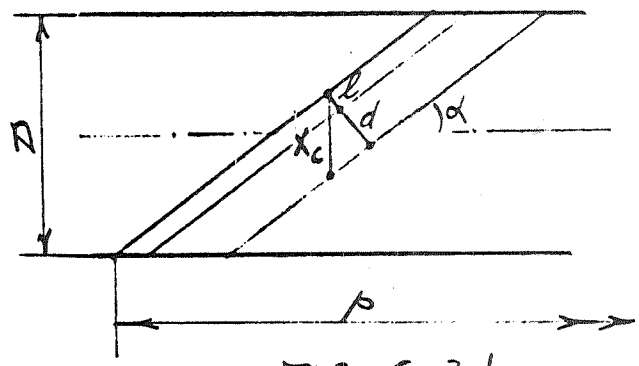


FIG. C-3-1

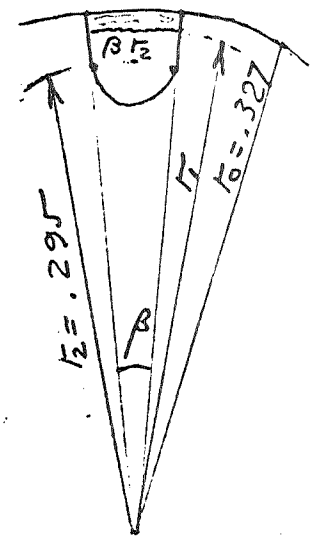


FIG. C-3-2

Eq. 14

For laminar annular liquid phase film at tube wall the weight flow per passage is derived from Eq. 4 or Eq. 4a. Note that circumferential liquid film connection in one passage is β radians. The equations 4 and 4a therefore, become:

$$W_0 = \frac{\beta \rho_0}{8\mu_0}\left[-\frac{1}{2}\left(r_0^4 - r_1^4\right) + r_0^2\left(r_0^2 - r_1^2\right)\right]\left(\frac{\partial p}{\partial x}\right)_0 \qquad \text{Eq. 15}$$

$$W_o = -\frac{\beta \rho_o}{16 \mu_o}\left(r_o^2 - r_1^2\right)^2 \left(\frac{\partial p}{\partial x}\right)_o \qquad \text{Eq. 15a}$$

Pressure gradient for laminar liquid annulus:

$$\left(\frac{\partial p}{\partial x}\right)_o = \frac{W_o}{\frac{\beta \rho_o}{8 \mu_o}\left[-\frac{1}{2}\left(r_o^4 - r_1^4\right) + r_o^2\left(r_o^2 - r_1^2\right)\right]}$$

$$= \frac{W_o}{\frac{\beta \rho_o r_o^4}{8 \mu_o}\left[-\frac{1}{2}\left(1 - \rho^4\right) + \left(1 - \rho^2\right)\right]}$$

or

$$= \frac{W_o}{\frac{\beta \rho_o}{16 \mu_o}\left(r_o^2 - r_1^2\right)^2} \qquad \text{Eq. 16}$$

$$= \frac{W_o}{\frac{\beta \rho_o r_o^4}{16 \mu_o}\left(1 - \rho^2\right)^2} \qquad \text{Eq. 16a}$$

where $\rho = \frac{r_1}{r_o}$ and W_o is the liquid phase flow rate per passage.

For turbulent vapor core in MPP:

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\xi_{int}\, \rho_1 V^2}{4 R_H\, 2 g_c} \qquad \text{Eq. 17}$$

where

$$R_H = \frac{\text{Area}}{\text{Perimeter}} = \frac{\pi(r_1^2 - r_2^2)\frac{\beta}{2\pi} + \frac{1}{2}\frac{\pi}{4}(\beta r_2)^2}{\beta r_1 + 2(r_1 - r_2) + \frac{1}{2}\pi\beta r_2} \qquad \text{Eq. 18}$$

Substitution of Eq. 18 into 17 results in:

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\xi_{int}\,\rho_1 V^2}{8 g_c}\;\frac{\beta r_1 + 2(r_1 - r_2) + \frac{1}{2}\pi\beta r_2}{(r_1^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2} \qquad \text{Eq. 19}$$

$$V^2 = \frac{V^2(\text{Area})^2\,\rho_1^2}{(\text{Area})^2\,\rho_1^2} = \frac{W_1^2}{\rho_1^2\left[(r_1^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2\right]^2} \qquad \text{Eq. 20}$$

Substitution of Eq. 20 into 19:

$$\left(\frac{\partial p}{\partial x}\right)_1 = \frac{\xi_{int}}{8 g_c}\,\frac{W_1^2}{\rho_1}\,\frac{\left[\beta r_1 + 2(r_1 - r_2) + \frac{1}{2}\pi\beta r_2\right]}{\left[(r_1^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2\right]^3} \qquad \text{Eq. 21}$$

$$= \frac{\xi_{int}}{8 g_c}\,\frac{W_1^2}{\rho_1}\,\frac{1}{r_0^5}\,\frac{\beta\rho + 2(\rho - \rho') + \frac{1}{2}\pi\beta\rho'}{\left[(\rho^2 - \rho'^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta\rho')^2\right]^3} \qquad \text{Eq. 22}$$

where $\rho = \frac{r_1}{r_0}$ and $\rho' = \frac{r_2}{r_0}$

The right sides of Eq. 16a and 22 are equal. Therefore

$$\frac{\xi_{int}}{8 g_c}\,\frac{W_1^2}{\rho_1}\,\frac{1}{r_0^5}\,\frac{\beta\rho + 2(\rho - \rho') + \frac{1}{2}\pi\beta\rho'}{\left[(\rho^2 - \rho'^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta\rho')^2\right]^3} = \frac{W_0}{\frac{\beta\rho_0 r_0^4}{16\mu_0}(1 - \rho^2)}$$

$$\frac{128}{\xi_{int}\beta}\,\frac{g_c r_0 \mu_0}{W_1}\,\frac{W_0}{W_1}\,\frac{\rho_1}{\rho_0}\,\frac{\left[(\rho^2 - \rho'^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta\rho')^2\right]^3}{\left[\beta\rho + 2(\rho - \rho') + \frac{1}{2}\pi\beta\rho'\right]} = (1 - \rho^2)^2 \qquad \text{Eq. 23}$$

The rearrangement of non-dimensional parameters yields:

$$\frac{W_0}{W_1}\frac{\rho_1}{\rho_0} = \frac{1}{\frac{W_1 \rho_0 \mu_1}{W_0 \rho_1 \mu_0}\frac{\mu_0}{\mu_1}} = \frac{1}{\mathcal{X}\frac{\mu_0}{\mu_1}} \qquad \text{Eq. 24}$$

$$\frac{g_c r_0 \mu_0}{W_1} = \frac{g_c r_0 \mu_1}{W_1}\cdot\frac{\mu_0}{\mu_1}$$

$$= \frac{r_0 \mu_1}{\bar{X}(W_1+W_0)}\frac{\mu_0}{\mu_1}$$

$$= \frac{N_1 N_2 r_0 \mu_1}{\bar{X} W_{TOT}}\frac{\mu_0}{\mu_1}$$

$$= \mathcal{Y}\frac{\mu_0}{\mu_1} \qquad \text{Eq. 25}$$

$g_c = \frac{lbf\text{-}ft}{lbm\text{-}sec^2}$

$\mu_{1,0} = \frac{lbf\cdot sec}{ft^2}$

$W_1 = lbm/sec$

$\mu_1 = \frac{lbm\text{-}ft}{hr}$

$W_1 = lbm/hr$

$$\mathcal{X} = \frac{W_1 \rho_0 \mu_1}{W_0 \rho_1 \mu_0} = \frac{\bar{X}\rho_0\mu_1}{(1-\bar{X})\rho_1\mu_0} \qquad \text{Eq. 26}$$

$$\mathcal{Y} = \frac{N_1 N_2 r_0 \mu_1}{12\bar{X} W_{TOT}} \qquad \text{Eq. 27}$$

Substitution of Eq. 24 and 25 into yields:

$$\frac{128}{\xi_{int}\beta}\frac{\mathcal{Y}}{\mathcal{X}}\frac{\left[(\rho^2-\rho'^2)\frac{\beta}{2}+\frac{\pi}{8}(\beta\rho_1)^2\right]^3}{\left[\beta\rho+2(\rho-\rho')+\pi\beta\rho'\right]} = 1-\rho^2)^2 \qquad \text{Eq. 28}$$

BODEPE notation of eq. 28 is:

FRINT = ξ_{int}
BETA = β
XXX(J) = $\mathcal{X}$
YYY(J) = $\mathcal{Y}$
RHOP = ρ'
RHOMPP = ρ
3.14159 = π

$\rho' < \rho < 1$

Using Eq. 22 and denoting its left side

$$\left(\frac{\partial p}{\partial x}\right)_{TP} = \left(\frac{\partial p}{\partial x}\right)_1$$

the two phase flow pressure drop factor can be expressed as follows:

$$\frac{\left(\frac{\partial p}{\partial x}\right)_{TP}}{\left(\frac{\partial p}{\partial x}\right)_{gas}} = \phi = \frac{\frac{\xi_{int}}{8 g_c}\,\frac{W_1^2}{\rho_1}\,\frac{\left[\beta r_1 + 2(r_1 - r_2) + \frac{1}{2}\pi\beta r_2\right]}{\left[(r_1^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2\right]^3}}{\frac{\xi_{tube}}{8 g_c}\,\frac{W_1^2}{\rho_1}\,\frac{\left[\beta r_0 + 2(r_0 - r_2) + \frac{1}{2}\pi\beta r_2\right]}{\left[(r_0^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2\right]^3}}$$

$$\phi = \frac{\xi_{int}}{\xi_{tube}}\left[\frac{\beta r_1 + 2(r_1 - r_2) + \frac{1}{2}\pi\beta r_2}{\beta r_0 + 2(r_0 - r_2) + \frac{1}{2}\pi\beta r_2}\right]\left[\frac{(r_0^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2}{(r_1^2 - r_2^2)\frac{\beta}{2} + \frac{\pi}{8}(\beta r_2)^2}\right]^3 \qquad \text{Eq. 29}$$

The NaK-to-Hg heat transfer path conductance is:

$$U = \frac{1}{R + \frac{1}{h_{Hg}}}$$

Where R is the thermal resistance between bulk NaK and the Hg tube ID.

The heat transfer provides:

$$U \Delta T_B = h_{Hg} \Delta T_F$$

$$\therefore \quad \Delta T_F = \frac{U \Delta T_B}{h_{Hg}} = \frac{\Delta T_B}{(R + 1/h_{Hg})\, h_{Hg}} \quad \frac{\Delta T_B}{R h_{Hg} + 1}$$

$$\Delta T_F = \frac{\Delta T_B}{R h_{Hg} + 1} \qquad \text{Eq. 36}$$

Rearrangement of Eq. 34 provides:

$$h_{Hg} = \frac{12 k_v}{De_h} \; \frac{6.6 n \left(\frac{1}{\theta_h} \bar{y}_L\right)^{8/15}}{B B^{2/5}} \; \frac{1}{\Delta T_F^{2/5}} \qquad \text{Eq. 37}$$

Denoting for computer coding purposes

$$CCC = \frac{12 k_v}{De_h} \; \frac{6.6 n \left(\frac{1}{\theta_h} \bar{y}_L\right)^{8/15}}{B B^{2/5}} \qquad \text{Eq. 38}$$

Utilizing Eq. 37 and 38 in Eq. 36 the latter becomes

$$\Delta T_F = \frac{\Delta T_B}{R \frac{CCC}{\Delta T_F^{2/5}} + 1}$$

$$\therefore \left(R \frac{CCC}{\Delta T_F^{3/5}} + 1\right) \Delta T_F = \Delta T_B$$

$$R \cdot CCC \cdot \Delta T_F^{3/5} + \Delta T_F = \Delta T_B$$

$$\underbrace{\Delta T_F}_{LHS} + \underbrace{(R)(CCC)\,\Delta T_F^{3/5} - \Delta T_B}_{RHS} = 0 \qquad \text{Eq. 39}$$

The BODEPE code notation is:

$DTXF(NN) = \Delta T_F$

$DTXB(NN) = \Delta T_B$

$RR = R$

$CCC = CCC$

$$TFROOT = \frac{LHS + RHS}{LHS}$$

C-5 SINGLE PHASE HEAT TRANSFER IN HELICAL FLOW PASSAGE.

The film heat transfer coefficient:

$$h_{SH} = h_{forced} + h_{free} \qquad \text{Eq. 40}$$

$$h_{free} = \underbrace{\frac{12\,k_v}{De_t} Nu_\ell (7.1) \frac{\beta^{1/3}}{Re_\ell^{.10} Pr^{.07}} \left(\frac{\pi D_1}{p}\right)^{2/3} \left(\frac{De_t}{De_\ell}\right)^{2/3}}_{FREE} \Delta T_F^{1/3} \qquad \text{Eq. 41}$$

h_{forced} is the coefficient determined from helical flow regime.

The Equation 36 also holds for superheat section. Consequently

$$\Delta T_F = \frac{\Delta T_B}{R\,h_{SH} + 1} \qquad \text{Eq. 42}$$

$$R\,h_{SH}\,\Delta T_F + \Delta T_F = \Delta T_B$$

$$R\,\Delta T_F \left(h_{forced} + FREE \cdot \Delta T_F^{1/3}\right) + \Delta T_F = \Delta T_B$$

$$R\,h_{forced}\,\Delta T_F + R \cdot FREE \cdot \Delta T_F^{1\frac{1}{3}} + \Delta T_F - \Delta T_B = 0.$$

$$R \cdot FREE \cdot \Delta T_F^{1\frac{1}{3}} + \left(R \cdot h_{forced} + 1\right) \Delta T_F - \Delta T_B = 0$$

$$\underbrace{\Delta T_F^{1.333} + \underbrace{\frac{R \cdot h_{forced} + 1}{R \cdot FREE}}_{GC\phi N2} \Delta T_F - \underbrace{\frac{\Delta T_B}{R \cdot FREE}}_{GC\phi N1}}_{RHS} = 0. \qquad \text{Eq. 43}$$

LHS

Eq. 43 is used in BODEPG code to provide solution for ΔT_F

THE FOLLOWING IS A DERIVATION OF THE THEORETICAL FRICTION FACTOR FOR FLUID FLOW IN A HELIX FLOW PASSAGE. IN THE DERIVATION NO ATTEMPT HAS BEEN MADE TO ESTABLISH A VELOCITY PROFILE FOR THIS TYPE OF FLOW. THE END RESULT IS USED AS A MEANS TO PREDICT THE PRESSURE DROP FOR FULL-SCALE MERCURY FLOW IN THE SNAP-8 BOILER.

THE PRESSURE DROP IN A SINGLE-FLUTED HELIX FLOW PASSAGE IS GIVEN BY THE DARCY-WEISBACH EQUATION AS:

$$\Delta P_H = f_H \frac{L_H}{D_H} \frac{U_H^2}{2g_c} \rho \qquad (1)$$

WHERE
f_H = HELIX FRICTION FACTOR
L_H = " FLOW PATH LENGTH
D_H = " EQUIVALENT DIAMETER
U_H = " FLOW VELOCITY
ρ = FLUID DENSITY
g_c = GRAVITY CONSTANT

SOLVING EQ. (1) FOR f_H:

$$f_H = \frac{\Delta P_H}{\rho} \frac{D_H}{L_H} \frac{2g_c}{U_H^2} \qquad (2)$$

IT IS POSTULATED THAT THE TOTAL PRESSURE DROP ΔP_H CAN BE WRITTEN:

$$\Delta P_H = \Delta P_a + \Delta P_r \qquad (3)$$

WHERE ΔP_a IS THE AXIAL FLOW LOSS AND ΔP_r IS THE ROTATIONAL LOSS FOR THE FLUID FLOWING IN THE R-θ PLANE.

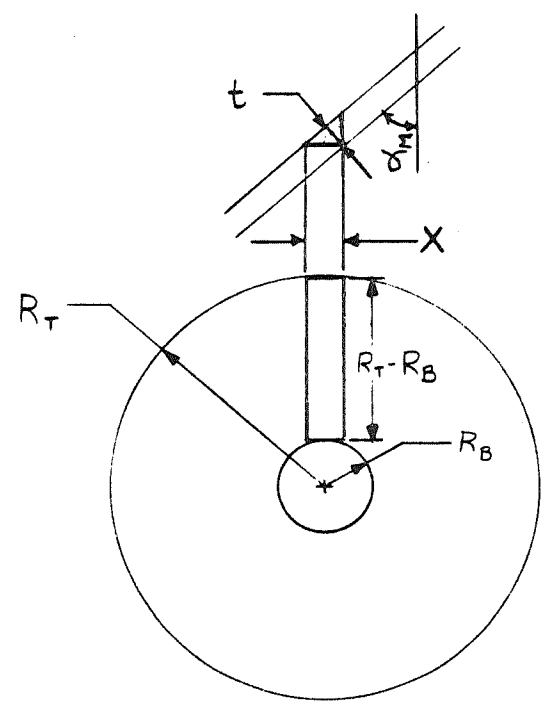
FOR THE AXIAL COMPONENT:

$$\Delta P_a = f_a \frac{L_a}{D_a} \frac{U_a^2}{2g_c} \rho \qquad (4)$$

WHERE

$f_a = .316 / Re_a^{.25}$
L_a = DISTANCE BETWEEN PRESSURE TAPS
D_a = AXIAL EQUIVALENT DIAMETER
U_a = " FLOW VELOCITY

THE AXIAL GEOMETRY IS OBTAINED IN THE FOLLOWING MANNER:



CONSTANT VALUES:
t = .06 IN.
R_B = .094 IN.
R_T = .326 IN.

FIGURE B-1

THEN

$$X = t / \cos\alpha_M \qquad (5)$$

$$A_a = \pi R_T^2 - \pi R_B^2 - X(R_T - R_B) \qquad (6)$$

THE FREE FLOW AXIAL AREA.

THE WETTED PERIMETER IS GIVEN BY:

$$P_a = 2\pi R_T + 2\pi R_B + 2(R_T - R_B) - 2X \qquad (7)$$

THE EQUIVALENT DIAMETER IS:

$$D_a = 4.0\,(A_a / P_a) \qquad (8)$$

THE ROTATIONAL PRESSURE LOSS TERM ΔP_r IS DEFINED BY THE ENERGY LOST IN OVERCOMING SHEAR AT THE TUBE WALL [REF. 1], SUCH THAT

$$\frac{\dot{w}}{\rho}\,\Delta P_r = \tau_w A_w v_w \qquad (9)$$

IT IS ASSUMED THAT THE FLOW IN THE RADIAL DIRECTION IS ZERO, OR:

$$v_r = 0$$

ALSO v_w = VELOCITY IN THE θ-DIRECTION
$= \tan\alpha_T\, U_a$
τ_w = SHEAR STRESS AT THE TUBE WALL
A_w = AREA OF THE TUBE WALL
$= \pi D_T L_a$

$$\tan\alpha_T = \frac{\pi D_T}{P}$$

$$\dot{w} = \rho A_a U_a$$

THE SHEAR STRESS AT THE TUBE WALL FOR TURBULENT ROTATING FLOWS IS EVALUATED IN TERMS OF v_w AS FOLLOWS. THE VELOCITY AT THE WALL RELATIVE TO SOME REFERENCE VELOCITY IN THE FLOW IS GIVEN BY KINNEY [REF. 2] AS

$$\frac{r_w v_w}{r_o v_o} \cong .66 \qquad (10)$$

AND

$$r_o v_o = \frac{r_w v_*}{2K_4} \qquad (11)$$

WHERE

r_o = REFERENCE RADIAL POSITION
v_o = " TANGENTIAL VELOCITY
r_w = RADIUS OF THE WALL
v_w = TANGENTIAL WALL VELOCITY
v_* = " SHEAR VELOCITY

$$= \sqrt{\frac{\tau_w g_c}{\rho}} \qquad (12)$$

$$K_4 = \text{CONSTANT} = .028 \qquad (13)$$

BY SUBSTITUTING (13), (12) AND (11) INTO (10) AND SOLVING FOR THE SHEAR STRESS RESULTS IN THE FOLLOWING EXPRESSION FOR τ_w

$$\tau_w = .0073\, \rho \frac{v_w^2}{g_c} \qquad (14)$$

SUBSTITUTING THE EXPRESSIONS FOR v_w, $\tan\alpha_T$, $\dot{\omega}$ A_w AND (14) INTO (9) GIVES

$$\Delta P_T = .0073 \left(\frac{\pi D_T}{P}\right)^3 \left(\frac{\pi D_T}{A_a}\right) L_a \frac{U_a^2}{g_c} \rho \qquad (15)$$

THE TERM, $\pi D_T / A_a$, IN EQUATION (15) CAN BE REPRESENTED BY

$$\pi D_T / A_a = \frac{4.0}{D_a}\left(\frac{D_T - t}{D_T + D_B}\right)$$

THEN

$$\Delta P_r = .0292\left(\frac{\pi D_T}{P}\right)^3\left(\frac{D_T - t}{D_T + D_B}\right)\frac{L_a}{D_a}\frac{U_a^2}{g_c}\rho \qquad (16)$$

SUBSTITUTING (16) AND (4) INTO (3), THE HELIX FLOW PRESSURE DROP IS

$$\Delta P_H = f_a \frac{L_a}{D_a}\frac{U_a^2}{2g_c}\rho + .0292\left(\frac{\pi D_T}{P}\right)^3\left(\frac{D_T - t}{D_T + D_B}\right)\frac{L_a}{D_a}\frac{U_a^2}{g_c}\rho \qquad (17)$$

PLACING THE ABOVE EXPRESSION FOR ΔP_H IN (2) GIVES

$$f_H = f_a \frac{D_H}{D_a}\frac{L_a}{L_H}\left(\frac{U_a}{U_H}\right)^2 + .0292\left(\frac{\pi D_T}{P}\right)^3\left(\frac{D_T - t}{D_T + D_B}\right)\frac{D_H}{D_a}\frac{L_a}{L_H}\left(\frac{U_a}{U_H}\right)^2 2.0$$

HOWEVER

$$\frac{L_a}{L_H} = \cos\alpha_M \qquad (18)$$

AND SINCE $\dot{w}_a = \rho A_a U_a = \dot{w}_H = \rho A_H U_H$, THEN

$$\frac{U_a}{U_H} = \frac{A_H}{A_a} \qquad (19)$$

AND $Re_a = Re_H \frac{A_H}{A_a} \frac{D_a}{D_H}$

THEN

$$f_a = \frac{.316}{Re_a^{.25}} = \left(\frac{.316}{Re_H^{.25}}\right)\left(\frac{A_H}{A_a}\right)^{-.25}\left(\frac{D_a}{D_H}\right)^{-.25} \qquad (20)$$

SUBSTITUTING (18), (19) AND (20) INTO THE EQUATION FOR f_H;

$$f_{H(THEO.)} = \left(\frac{.316}{Re_H^{.25}}\right)\left(\frac{A_H}{A_a}\right)^{1.75}\left(\frac{D_H}{D_a}\right)^{1.25}\cos\alpha_M + .0584\left(\frac{\pi D_T}{P}\right)^3\left(\frac{D_T - t}{D_T + D_B}\right)\left(\frac{A_H}{A_a}\right)^2\left(\frac{D_H}{D_a}\right)\cos\alpha_M$$

01-071-002

QUADRILLE WORK SHEET

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE _____

SUBJECT HELIX FRICTION FACTOR BY G. LOMBARD WORK ORDER _____

REFERENCE [1]: SMITHBERG, E., LANDIS, F., "FRICTION AND FORCED CONVECTION HEAT-TRANSFER CHARACTERISTICS IN TUBES WITH TWISTED TAPE SWIRL GENERATORS." TRANS. ASME SERIES C JOURNAL OF HEAT TRANSFER, FEBRUARY 1964 p.p. 39-49.

REFERENCE [2]: KINNEY, R.B., "UNIVERSAL VELOCITY SIMILARITY IN FULLY TURBULENT ROTATING FLOWS" TRANS. ASME SERIES E, VOL 34, JOURNAL OF APPLIED MECHANICS, JUNE 1967, PP 437-442.

NOMENCLATURE

A_{LIN}	-	Linear flow crossection area
D_1	-	Tube ID
De_t	-	Equivalent diameter, tangential
De_l	-	Equivalent diameter, linear
d	-	Channel width in plug insert
g_c	-	Gravitational constant
h_{fv}	-	Vaporization heat
h_{forced}	-	Forced convection heat transfer coefficient
h_{free}	-	Free convection heat transfer coefficient
h_{Hg}	-	Mercury side heat transfer coefficient
h_{SH}	-	Vapor heat transfer coefficient
k_f	-	Thermal conductivity, liquid mercury
k_v	-	Thermal conductivity, vapor mercury
N_1	-	Number of tubes in boiler
N_2	-	Number of flow passages in plug insert
Nu	-	Nusselt modulus
Nu_l	-	Nusselt modulus, linear
n_o	-	Initial droplet population per diameter length
n	-	Local droplet population per diameter length
p	-	Pitch, pressure
Pr	-	Prandtl modulus
R	-	Thermal resistance between bulk NaK and mercury tube ID
r_o	-	Tube ID radius
r_1	-	Liquid-vapor interface radius in divided two-phase flow model
r_2	-	Radius (Figure C-2)
r	-	Radius

$\bar{u}_1$	-	Velocity, mean
u_{TV}	-	Vapor tangential velocity
V_o	-	Mean velocity
W_o	-	Liquid phase flow rate
W_1	-	Vapor phase flow rate
W_{TOT}	-	Total flow rate
$\bar{x}$	-	Mean vapor quality
x_o	-	Initial vapor quality
$\bar{y}_1$	-	Mean moisture content
α	-	Helical angle, $\alpha = \tan^{-1}(\pi D/p)$
β	-	Angle, volumetric expansion
ξ_{int}	-	Liquid-vapor interface frictional pressure drop coefficient in divided two-phase flow regime
ξ_{tube}	-	Frictional pressure drop coefficient at tube wall
$\mu_{f_1}\mu_o$	-	Dynamic viscosity, liquid
$\mu_{v_1}\mu$	-	Dynamic viscosity, vapor
$\rho = r_1/r_o$		
ρ_f, ρ_o	-	Density, liquid
ρ_v, ρ_1	-	Density, vapor
Φ	-	Two-phase pressure drop factor
τ	-	Shear stress